Synthesis of a Molecular Charm Bracelet via Click Cyclization and Olefin Metathesis Clipping

Paul G. Clark[†], Erin N. Guidry[†], Wing Yan Chan[†], Wayne E. Steinmetz[‡], and Robert H. Grubbs*[,†]

The Arnold and Mabel Beckman Laboratory of Chemical Synthesis, Division of Chemistry and Chemical Engineering, California Institute of Technology, Pasadena, California 91125 and Chemistry Department, Pomona College, 645 N. College Avenue, Claremont, CA 91711

rhg@caltech.edu

Supporting Information
Experimental procedures and characterization data (^{1}H and ^{13}C and 2D NMR, IR, HRMS, GPC) for all compounds and their precursors.

General Information. NMR spectra were obtained on either a Mercury 300 MHz spectrometer, an INOVA 500 MHz spectrometer equipped with an AutoX broadband probe with z-gradients, or an INOVA 600 MHz spectrometer equipped with an inverse HCN triple resonance probe with x,y,and z-gradients. All spectrometers were running Varian VNMRJ software. Chemical shifts for both ^{1}H and ^{13}C spectra are reported in per million (ppm) relative to Si(CH3)4 (δ=0) and referenced internally to the proteo solvent resonance. Multiplicities are abbreviated as follows: singlet (s), doublet (d), triplet (t), quartet (q), quintet (qt), septuptlet (sp), multiplet (m), and broad (br). MestReNova NMR 5.3.2 software was used to analyze all NMR spectra. Molecular mass calculations were performed with ChemBioDraw Ultra 11.0.1 (Cambridge Scientific). Mass spectrometry measurements (FAB, EI, and MALDI) were performed by the California Institute of Technology Mass Spectrometry Facility. Analytical thin-layer chromatography (TLC) was performed using silica gel 60 F254 precoated plates (0.25 mm thickness) with a fluorescent indicator. Visualization was performed using UV and iodine stain. Flash column chromatography was performed using silica gel 60 (230-400 mesh) from EM Science. Gel permeation chromatography (GPC) was carried in THF out on two PLgel 10 μm mixed-B LS columns (Polymer Labs) connected in series with a DAWN EOS multiangle laser light scattering (MALLS) detector and an Optilab DSP differential refractometer (both from Wyatt Technology). No calibration standards were used, and *dn/dc* values were obtained for each injection assuming 100% mass elution from the columns. IR was obtained on a Perkin-Elmer BX-II FTIR spectrometer using thin-film techniques on NaCl plates.

[†] California Institute of Technology
[‡] Pomona College

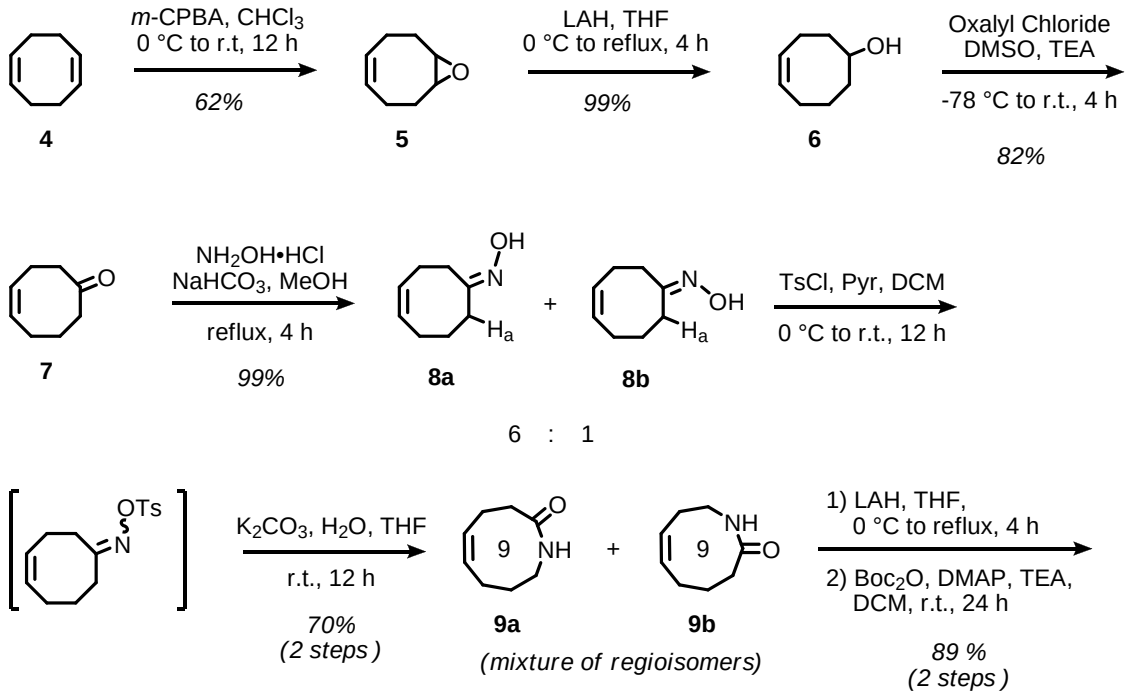
DOSY Information. The 2D-DOSY measurements were made at 400 MHz on a Bruker DPX spectrometer with a variable-temperature dual $^{1}H/^{13}C$ dual probe and a DPX Avance console. Accessories relevant to the experiment included a GCU gradient shaping card, a GREAT gradient amplifier with a maximum gradient current of 10 A, and a single-axis gradient coil on the probe. Bruker XWINNMR was used to control the spectrometer and process the data. The execution of the experiment which employs an automation program in addition to the ledbpgp2s pulse sequence is described in a special Bruker document.[1] The coil constant for the probe was determined by applying the BP-LDE pulse sequence, which was developed for measuring the translational diffusion constant D_T, on a sample with a known D_T. Longsworth accurately measured D_T of HDO in D_2O.[2] Accordingly, the HDO signal in 99.96 atom-% D2O was observed with the BP-LDE method of Stejskal and Tanner modified by Wu et al., which employs bipolar gradient pulses and the LED pulse sequence.[3] The DOSY measurements were based on the 2D version of the BP-LDE method. The acquisition parameters were SW, 10.00 ppm; TD, 16k; NS, 512; AQ, 2.0447731 s; Δ (the diffusion time), 500 ms; τ (the gradient recovery), 0.2 ms; Te (the eddy current delay), 5 ms; $\delta/2$ (the gradient pulse), 0.5 ms. Sinusoidal gradient pulses and a quadratic ramp in gradient current were employed. A quadratic ramp of 16 gradient currents ranging from 0.354% to 21.235% was employed.

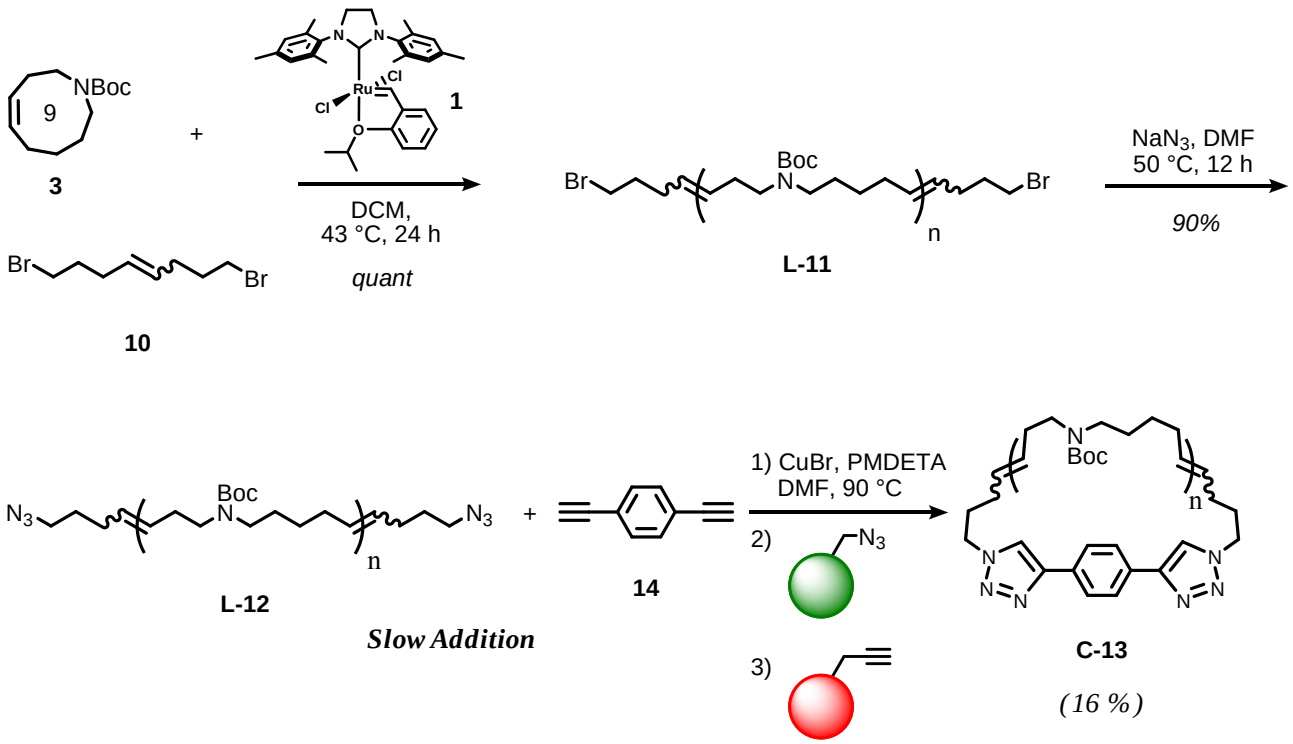
Materials and Methods. Anhydrous N,N-dimethylformamide (DMF) was obtained from Acros (99.8% pure, Acroseal). Dry tetrahydrofuran (THF) and dichloromethane (DCM) were purified by passage through solvent purification columns.[4] All water was deionized. *cis*-1,5-Cyclcooctadiene (**4**, 99%), 5-bromo-1-pentene (95%), and 1,4-diethynylbenzene (**14**, 96%), and nitromethane (95+%, ACS reagent) were purchased from Aldrich and used as received. Anhydrous potassium carbonate (J. T. Baker, 99.6%) was used as received. Grubbs 2nd Generation catalyst $(H_2IMes)(PCy_3)(Cl)_2Ru{=}CHPh$ and Grubbs-Hoveyda 2nd Generation isopropoxybenzylidene catalyst $(H_2IMes)(Cl)_2RuCH(o\text{-}OiPrC_6H_4)$ (**1**) were obtained as a generous gift from Materia, Inc. All other compounds were purchased from Acros or Aldrich and used as received.

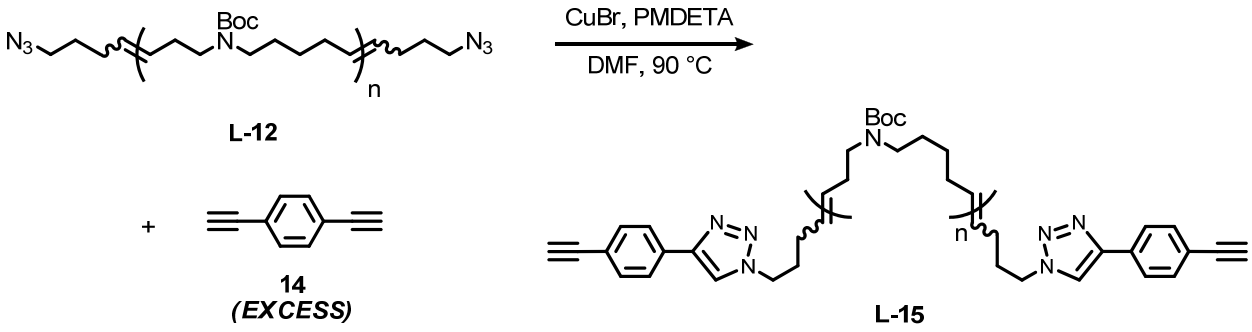
General Freeze-Pump-Thaw Procedure. A flask charged with reagents and solvent was frozen with liquid nitrogen. After the solution had frozen, the headspace of the flask was evacuated under vacuum. The flask was sealed and allowed to thaw to room temperature. The headspace of the flask was then backfilled with argon. The flask was sealed and the reaction mixture frozen again with liquid nitrogen. This process was repeated twice. On the third cycle, the solution was frozen and the headspace evacuated and backfilled with argon. Catalyst was quickly added to the top of the frozen solution, the headspace was again evacuated, and the solution allowed to warm to room temperature. The solution was backfilled with argon, refrozen, and subjected to another cycle for a total of four freeze-pump-thaw cycles.

References:

1) Kerssebaum, R. DOSY and Diffusion by NMR, Bruker Biospin, Rheinstetten, 2002.
2) Longsworth, L. G. The Mutual Diffusion of Light and Heavy Water. *J. Phys. Chem*. **1960**, *64*, 1914-1917.
3) Wu, D.; Chen, A.; Johnson, C. S. An Improved Diffusion-ordered Spectroscopy Experiment Incorporating Bipolar-Gradient Pulses. *J. Magn. Reson. A.* **1995**, *115*, 260-264.
4) Pangborn, A. B.; Giardello, M. A.; Grubbs, R. H.; Rosen, R. K.; Timmers, F. J. *Organometallics* **1996**, *15*, 1518-1520.


m-CPBA, CHCl3
0 °C to r.t, 12 h
62%
LAH, THF
0 °C to reflux, 4 h
99%
Oxalyl Chloride
DMSO, TEA
-78 °C to r.t., 4 h
82%
4
5
6
NH2OH•HCl
NaHCO3, MeOH
reflux, 4 h
99%
TsCl, Pyr, DCM
0 °C to r.t., 12 h
7
8a
8b
6 : 1
K2CO3, H2O, THF
r.t., 12 h
70%
(2 steps)
9a
9b
(mixture of regioisomers)
1) LAH, THF,
0 °C to reflux, 4 h
2) Boc2O, DMAP, TEA,
DCM, r.t., 24 h
89 %
(2 steps)
3


3
1
DCM,
43 °C, 24 h
quant
10
L-11
NaN3, DMF
50 °C, 12 h
90%
L-12
Slow Addition
14
1) CuBr, PMDETA
DMF, 90 °C
2)
3)
C-13
(16 %)



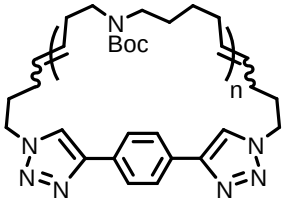
L-12

+

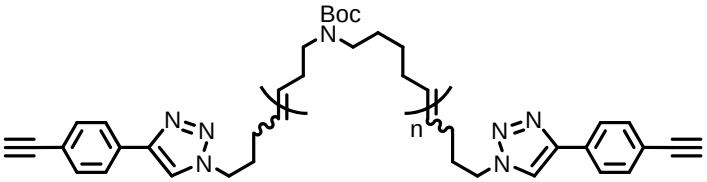
14
(EXCESS)

L-15

(48%)



C-13



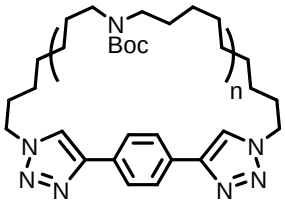
L-15

$Rh(PPh_3)_3Cl$
H_2 (800 psi), THF
50 °C, 24 h

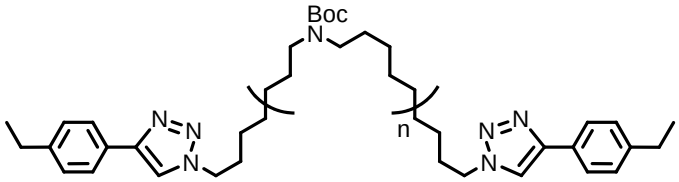
(77%)

$Rh(PPh_3)_3Cl$
H_2 (800 psi), THF
50 °C, 24 h

(54%)



C-16



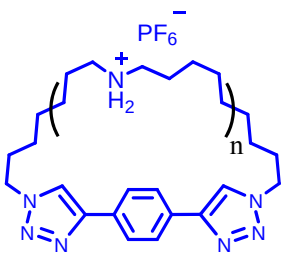
L-18a

1) TFA, DCM
r.t., 4 h

2) NH_4PF_6, MeOH
r.t., 12 h

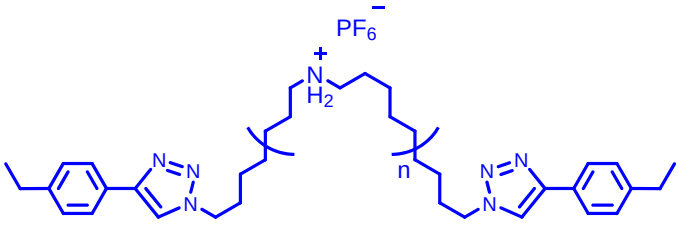
1) TFA, DCM
r.t., 4 h

2) NH_4PF_6, MeOH
r.t., 12 h



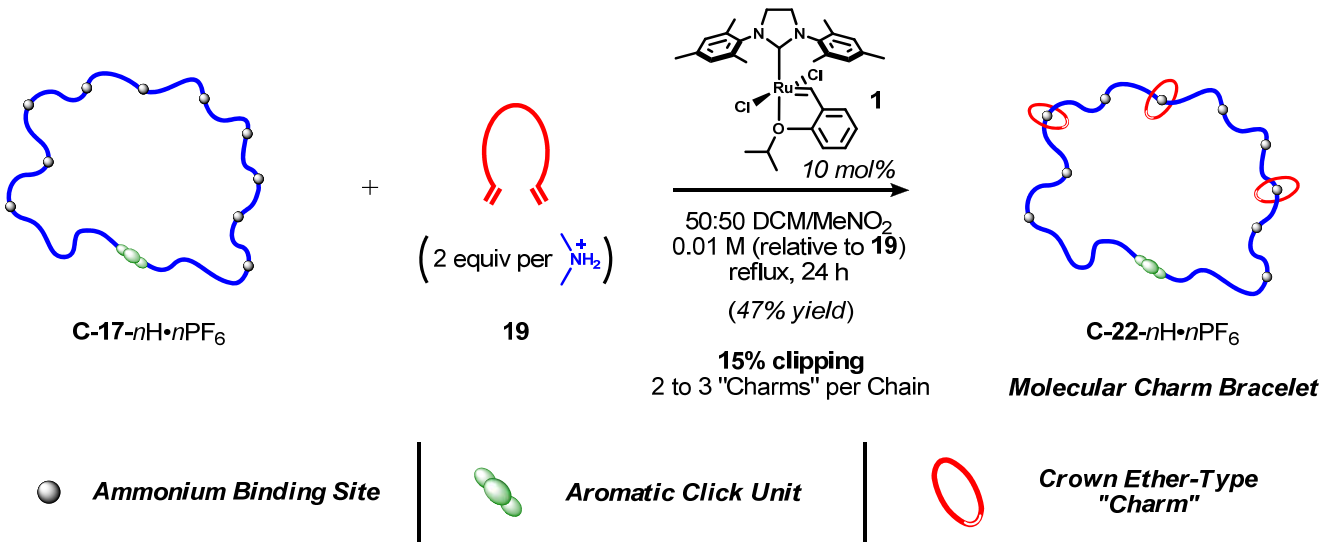
C-17-*n*H•*n*PF_6

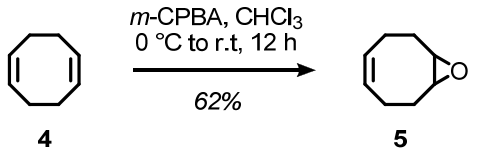
(67%)
2 steps



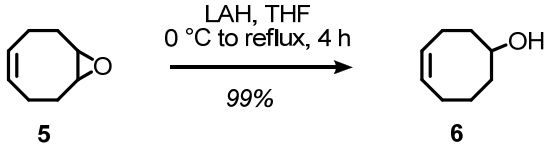
L-18-*n*H•*n*PF_6

(91%)
2 steps

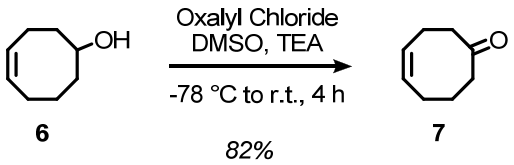

C-17-nH•nPF6
(2 equiv per NH2+)
19
Ru
Cl
Cl
O
1
10 mol%
50:50 DCM/MeNO2
0.01 M (relative to 19)
reflux, 24 h
(47% yield)
15% clipping
2 to 3 "Charms" per Chain
C-22-nH•nPF6
Molecular Charm Bracelet
Ammonium Binding Site
Aromatic Click Unit
Crown Ether-Type "Charm"



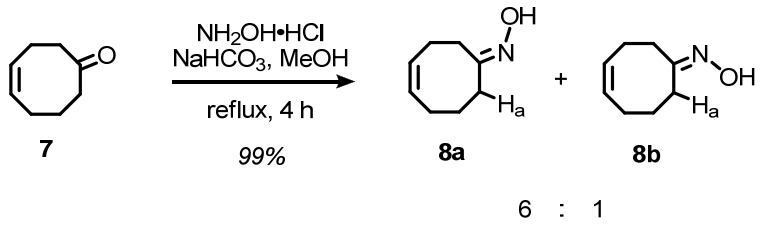
Cyclcooctene monoepoxide (**5**). To a two-liter round bottom flask equipped with a stir bar was added *cis*-1,5- cyclooctadiene (50.0g, 0.41 mol, 1 eq). The flask was fitted with an addition funnel, and the round bottom flask was cooled in an ice bath. A solution of 3-chloroperoxybenzoic acid (124.5 g, 0.556 mol, 1.36 eq) in chloroform (1 L) was added slowly over 2 hours. The reaction was allowed to stir at room temperature overnight, then filtered. The solution was washed in a separatory funnel with saturated aqueous sodium bisulfate, then saturated aqueous sodium bicarbonate, then saturated sodium chloride. The organic layer was dried ($MgSO_4$), filtered, and evaporated under reduced pressure. The crude oil was subjected to purification via flash chromatography (SiO_2: eluting in 10:1 hexanes to ethyl acetate) to afford monoepoxide **5** as a clear, colorless oil (31.985 g, 62% yield). ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.55 (m, 2H), 3.02 (m, 2H), 2.42 (m, 2H), 2.20-1.90 (m, 6H). ^{13}C NMR (76 MHz, $CDCl_3$): δ 129.06, 56.95, 28.31, 23.89. HRMS-EI (m/z): [M + H] calcd for $C_8H_{12}O$, 124.0888; found 124.0891.



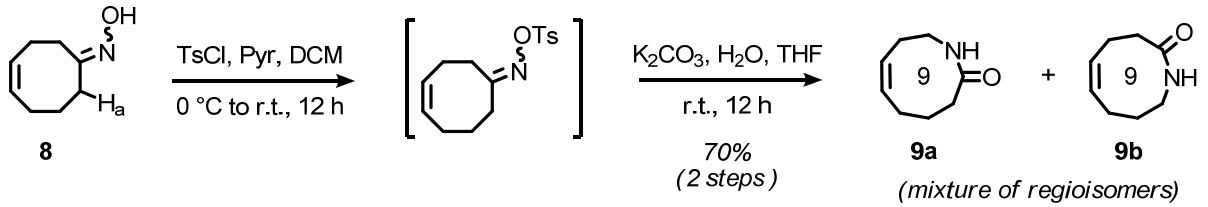
Cycloct-4-enol (**6**). To an oven-dried two-neck two-liter flask equipped with a stir bar, septum, and reflux condenser under argon was added lithium aluminum hydride powder (28.3 g, 0.747 mol, 3 eq). The flask was cooled in an ice bath, and dry THF (1 L) was added via cannulation. To this slurry, and at 0 °C, was slowly added cyclooctene monoepoxide **5** (30.90 g, 0.249 mol, 1 eq) dissolved in dry THF (100 ml). The reaction was heated to reflux for 4 hours, then cooled to 0 °C. Water (28.3 ml) was added dropwise to the slurry, then a solution of 15 % aqueous sodium hydroxide (28.3 ml), and, finally, additional water (84.9 ml). This solution was allowed to stir at room temperature for 4 hours, and the gray salts slowly became white. An excess of celite and $MgSO_4$ were added and allowed to stir for 30 minutes. The salts were filtered, and the solution was concentrated by rotary evaporation to afford the desired alcohol **6** as a clear oil (31.29 g, 99% yield). The product was used with no further purification. ^{1}H NMR (500 MHz, $CDCl_3$): δ 5.75-5.50 (m, 2H), 3.80 (m, 1H), 2.30 (m, 1H), 2.14 (m, 3 H), 1.97-1.80 (m, 2H), 1.77-1.58 (m, 2H), 1.52 (m, 2H). ^{13}C NMR (126 MHz, $CDCl_3$): δ 130.34, 129.73, 72.93, 37.91, 36.47, 25.85, 25.07, 22.98. HRMS-EI (m/z): [M + H] calcd for C_8H_{14}, 126.1045; found 126.1043.



Cyclooct-4-enone (**7**). To an oven-dried two-neck two-liter flask equipped with a stir bar and fitted with an oven-dried addition funnel was added, under argon, dry dichloromethane (DCM, 850 ml) and dimethylsulfoxide (71.0 g, 0.909 mol, 4 eq), and the solution was cooled to -78 °C. Oxalyl chloride (57.7 g, 0.454 mol, 2 eq) was slowly added to the reaction, and the solution was allowed to stir for 30 minutes. Alcohol **6** (28.66 g, 0.227 mol, 1 eq) was added to the reaction as a solution in dry DCM (150 ml) over 30 minutes. After stirring for another 30 minutes, anhydrous triethylamine (230 g, 2.27 mol, 10 eq) was added. The reaction was stirred for 10 minutes at -78 °C, then warmed to room temperature and stirred for 30 minutes. The salts were filtered, and the solvent removed by rotary evaporation. The crude oil was purified first by flash chromatography (SiO_2: eluting in a gradient of 20:1 hexanes to acetone, then 10:1, then 4:1, then 1:2), and then via reduced pressure fractional distillation through a Vigreux column (10.0 torr, bp = 75-85 °C) to afford ketone **7** as a clear oil (23.134 g, 82%). ^{1}H NMR (500 MHz, $CDCl_3$): δ 5.66 (m, 2H), 2.43 (m, 6H), 2.13 (m, 2H), 1.56 (m, 2H). ^{13}C NMR (126 MHz, $CDCl_3$): δ 214.91, 130.95, 130.41, 47.43, 40.54, 26.50, 24.11, 22.02. HRMS-EI (m/z): [M + H] calcd for $C_8H_{12}O$, 124.0888; found 124.0847.

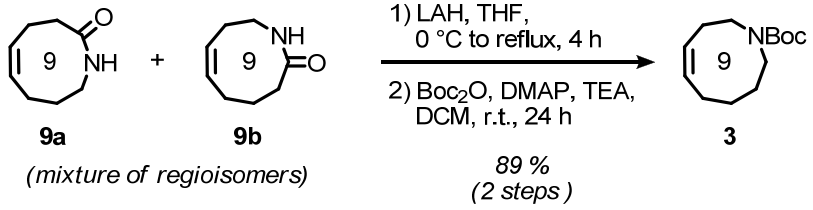


Cyclooct-4-enone oxime (**8**). To a one-liter round bottom flask equipped with a stir bar and reflux condenser was added ketone **7** (22.12 g, 0.178 mol, 1 eq), hydroxylamine hydrochloride (18.56 g, 0.267 mol, 1.5 eq), sodium bicarbonate (22.6 g, 0.269 mol, 1.51 eq), and methanol (600 ml). The solution was heated to reflux for 4 hours, then cooled to room temperature. The methanol was removed by rotary evaporation, and the residue redissolved in ethyl ether (300 ml) and partitioned with water (500 ml). The aqueous layer was extracted with fresh ether (300 ml x 1, 100 ml x 2), and the combined organic layers washed with fresh water (500 ml), dried ($MgSO_4$), and filtered. The solvent was removed to give oxime **8** as a white crystalline solid (24.56 g, 99%). The product was used with no further purification. ^{1}H NMR (600 MHz, $CDCl_3$): δ 8.30 (br s, 1H), 5.66 (m, 2H), 2.57 (m, 0.3H, **8b**), 2.42 (m, 1.7H, **8a**), 2.28 (m, 4H), 2.11 (m, 2 H), 1.71 (m, 1.7H, **8a**), 1.61 (m, 0.3H, **8b**). ^{13}C NMR (76 MHz, $CDCl_3$): δ 162.65, 131.28, 129.84, 36.25, 28.25, 26.43, 23.93, 22.76. HRMS-EI (m/z): [M + H] calcd for $C_8H_{13}NO$, 139.0997; found, 139.0999.



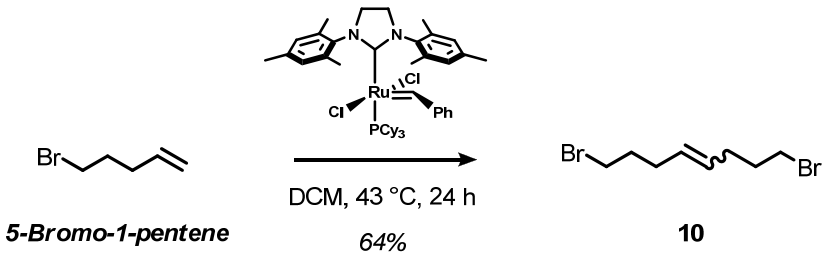
Lactam (**9a** and **9b**). Synthesis of the tosyl oxime intermediate was performed batchwise. Oxime **8** (12.00 g, 86.2 mmol, 1 eq) was added to a two-liter round bottom flask equipped with a stir bar and addition funnel, then dissolved in DCM (900 ml). Pyridine (17.05 g, 215.5 mmol, 2.5 eq) and dimethylaminopyridine (a few crystals) were added. Tosyl chloride (24.65 g, 129.3 mmol, 1.5 eq) was dissolved in DCM (500 ml) and added to the addition funnel. The reaction mixture was cooled to 0 °C, and the tosyl chloride solution was slowly added to reaction over 2 hours. After addition was complete, the reaction was warmed to room temperature and allowed to stir for 1 day. The reaction was poured into a separatory funnel and partitioned with water (500 ml). The aqueous layer was extracted with fresh chloroform (4 x 100 ml), and the combined organic layers were dried ($MgSO_4$), filtered, and evaporated to dryness under reduced pressure. The tosyl oxime product was used in the next reaction with no further purification.

Tosyl oxime (25.29 g, 86.21 mmol, 1 eq) was added to a flask, and a solution of aqueous potassium carbonate (11.32 g, 81.90 mmol, 0.95 eq in 688 ml H_2O) was added. This was allowed to stir for 30 seconds, at which point tetrahydrofuran (360 ml) was added. The solution became bright yellow over several hours. The reaction was allowed to stir at room temperature for 1 day, then poured into a separatory funnel and partitioned between water and chloroform (250 ml). The aqueous layer was extracted with fresh chloroform (4 x 100 ml), and the combined organic layers were dried ($MgSO_4$), filtered, and evaporated to dryness under reduced pressure. The product was purified by flash chromatography (SiO_2: eluting in 2:1 hexanes to acetone) to give the lactams **9a** and **9b** as a white, fluffy powder (8.488 g, 70 % overall yield from oxime **8**). ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.33 (br s, 0.7 H), 6.15 (br s, 0.3 H) 5.70-5.20 (m, 2H), 3.50 (m, 0.3H), 3.10 (m, 1.4H), 2.60 (m, 0.3H), 2.30-1.80 (br m, 6H), 1.80-1.60 (br m, 2H). ^{13}C NMR (76 MHz, $CDCl_3$): δ 178.07, 176.88, 134.12, 131.45, 128.82, 124.97, 42.17, 38.89, 36.39, 29.41, 28.86, 27.67, 26.72, 25.55, 25.41. HRMS-EI (m/z): [M + H] calcd for $C_8H_{13}NO$, 139.0997; found 139.0991.

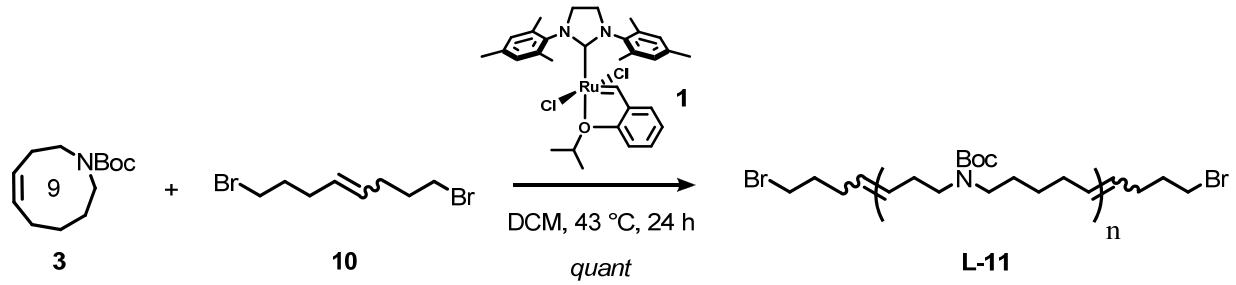


Boc-Amine (**3**). To an oven-dried flask equipped with a stir bar, septum, and reflux condenser under argon was added lithium aluminum hydride powder (3.27 g, 37.95 mmol, 3 eq). The flask was cooled in an ice bath, and dry THF (287 ml) was added via cannulation. To this slurry, and

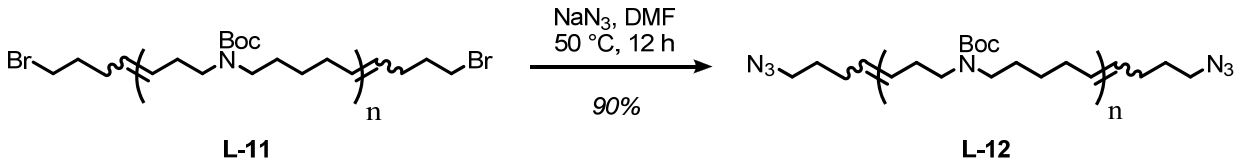
at 0 °C, was slowly added lactams **9a** and **9b** (3.50 g, 28.7 mmol, 1 eq) dissolved in dry THF (25 ml). The reaction was heated to reflux for 4 hours, then cooled to 0 °C. To quench the reaction, water (3.27 ml), 15 % $NaOH/H_2O$ (3.27 ml), and water (9.81 ml) were added sequentially, and the solution allowed to stir for 1 hour. An excess of celite and $MgSO_4$ were added, and the slurry was allowed to stir for 15 min. The salts were filtered, and the solvent removed by rotary evaporation to yield a clear oil. The crude amine was redissolved in DCM (287 ml), and dimethylaminopyridine (a few crystals), triethylamine (8.71 g, 86.1 mmol, 3 eq), and di-*tert*-butyl dicarbonate (6.89 g, 31.6 mmol, 1.1 eq) were added. The solution was stirred at room temperature for 12 hours, then poured into a separatory funnel and diluted with water (250 ml). The aqueous layer was extracted with fresh DCM (2 x 50 ml), and the combined organic layers were dried ($MgSO_4$), filtered, and evaporated to dryness. The crude oil was purified by flash chromatography (SiO_2: eluting in a gradient from 16:1 hexanes to acetone, then 8:1) to afford the boc-amine monomer **3** as a clear oil (5.10 g, 89% overall yield from lactams **9a** and **9b**). Though ^1H NMR analysis of the crude reaction mixture showed the presence of both regioisomers, only regioisomer **3** was isolated after column chromatography. The reported NMR and MS data are for this pure regioisomeric form. ^1H NMR (500 MHz, $CDCl_3$): δ 5.76 (tt, J = 8.0 Hz, 1H), 5.43 (m, 1H), 3.36 (t, J = 5.7 Hz, 1H) 3.27 (t, J = 5.7 Hz, 1H), 3.15-3.05 (m, 2H), 2.33-2.22 (m, 2H), 2.12 (q, J = 7.1 Hz, 2H), 1.60-1.48 (br m, 6H), 1.46 (s, 9H). ^{13}C NMR (151 MHz, $CDCl_3$): δ 156.09, 155.51, 131.99, 131.37, 129.16, 128.58, 79.23, 79.12, 48.42, 48.26, 47.89, 47.82, 28.63, 28.58, 26.91, 26.77, 26.68, 25.63, 25.54, 25.38, 24.29, 23.58. HRMS-EI (m/z): [M + H] calcd for $C_{13}H_{23}NO_2$, 225.1729; found 225.1729.



Dibromo Chain-Transfer Agent (**10**). To an oven dried vial equipped with a stir bar and fitted with a septa screw-cap and under argon atmosphere was added 5-bromo-1-pentene (0.5 g, 3.36 mmol, 2 eq) and dry DCM (16.9 ml). This solution was sparged with argon with stirring for 15 minutes, and Grubbs first generation ruthenium olefin metathesis catalyst $(H_2IMes)(PCy_3)(Cl)_2Ru{=}CHPh$ (0.1424 g, 0.168 mmol, 5 mol%) was quickly added. Sparging was continued for an additional 5 minutes, and the reaction heated to 41 °C for 24 h. The reaction was cooled to room temperature, and excess ethyl vinyl ether was added. Stirring was continued for 30 minutes, and the solution evaporated to dryness. The crude oil was purified by flash chromatography (SiO2: eluting in hexanes) to afford the dibromo chain-transfer agent **10** as a clear oil (0.291 g, 64% yield). ^1H NMR (300 MHz, $CDCl_3$): δ 5.42 (m, 2H), 3.38 (m, 4H), 2.52-2.05 (m, 4H), 2.05-1.75 (m, 4H). ^{13}C NMR (76 MHz, $CDCl_3$): δ 129.97, 129.49, 33.46, 32.46, 32.26, 31.03, 25.93. HRMS-EI (m/z): [M + H] calcd for $C_8H_{14}Br_2$, 269.9442; found 269.9432.

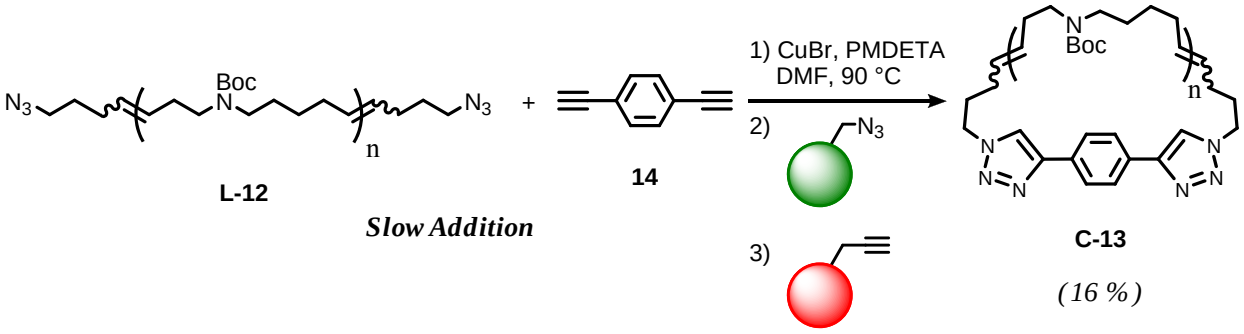


Linear Dibromo Homotelechelic Polymer (**L-11**). To an oven-dried vial equipped with a stir bar and fitted with a septa screw-cap and under argon atmosphere was added monomer **3** (2.0000 g, 8.875 mmol, 180 eq), dibromo CTA **10** (0.1331 g, 0.4931 mmol, 10 eq), and dry DCM (8.9 ml, 1.0 M with respect to monomer). This solution was sparged with argon for 15 minutes, and Grubbs-Hoveyda 2nd Generation isopropoxybenzylidene catalyst $(H_2IMes)(Cl)_2RuCH(o\text{-}O\textit{i}PrC_6H_4)$ **1** (30.9 mg, 49.3 μmol, 1 eq) was quickly added. Sparging was continued for 10 minutes, and the reaction was then heated to 43 °C for 24 h. The reaction was cooled to room temperature, and excess ethyl vinyl ether was added. After stirring for 10 minutes, the solvent was removed under reduced pressure. The resulting viscous oil was added slowly to a vigorously stirring reservoir of hexanes (50 ml). The dark-colored precipitate was filtered off, and the solution was evaporated to dryness to afford linear dibromo telechelic polymer **L-11** as a pale brown viscous oil (2.01 g, quant. yield). ^{1}H NMR (600 MHz, $CDCl_3$): δ 5.35 (br m, 2H), 3.38 (m, 0.2H), 3.12 (br m, 4H), 2.16 (m, 2H), 1.96 (m, 2H), 1.63 (br m, 2H), 1.42 (s, 9H), 1.28 (m, 2H). ^{13}C NMR (126 MHz, $CDCl_3$): δ 155.72, 132.34, 130.43, 129.19, 127.24, 79.17, 47.23, 33.48, 32.62, 31.73, 31.04, 30.19, 28.71, 26.92. FTIR (NaCl, cm^{-1}): 2973.03, 2929.73, 2858.16, 1693.70, 1468.26, 1415.23, 1390.42, 1365.16, 1250.33, 1166.43, 968.18, 883.93, 771.79. GPC (THF): M_n = 4.1 kDa; M_w = 6.1 kDa; PDI = 1.49.



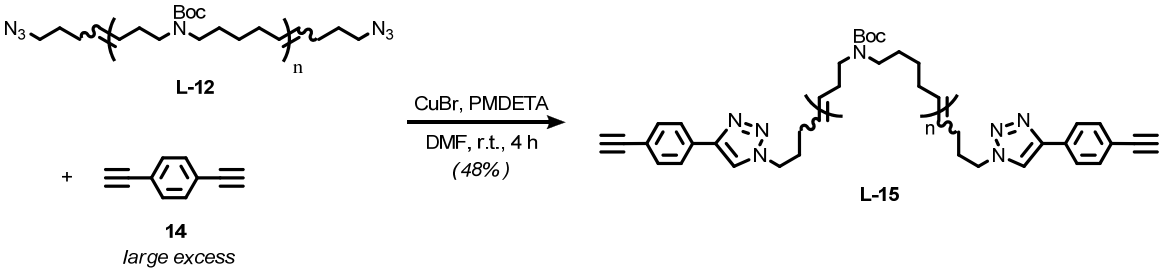
Linear Diazide Homotelechelic Polymer (**L-12**)**.** To an oven-dried vial equipped with a stir bar and fitted with a septa screw-cap and under argon atmosphere was added linear dibromo telechelic polymer **L-11** (1.8000 g, 0.450 mmol, 1 eq) and DMF (18 ml). Once all the polymer had dissolved, sodium azide (180 mg, 2.7 mmol, 6 eq, 3 eq per bromide) was added in one portion. The reaction was heated to 50 °C for 12 hours, then cooled to room temperature. The solution was added to a separatory funnel and partitioned between water (50 ml) and ether (50 ml). The aqueous layer was extracted with fresh ether (3 x 25 ml), and the combined organic layers further washed with fresh water (2 x 25 ml). The organic layer was dried (MgSO4), filtered, and evaporated to dryness under reduced pressure to give the linear diazide telechelic polymer **L-12** as a pale orange oil (1.6235g, 90% yield). ^{1}H NMR (600 MHz, $CDCl_3$): δ 5.35 (br

m, 2H), 3.23 (m, 0.2H), 3.12 (br m, 4H), 2.16 (m, 2H), 1.96 (m, 2H), 1.52 (br m, 2H), 1.42 (s, 9H), 1.28 (m, 2H). ^{13}C NMR (126 MHz, $CDCl_3$): δ 155.72, 132.34, 130.42, 129.19, 127.28, 79.17, 77.48, 77.23, 76.98, 50.98, 47.25, 32.61, 31.75, 30.24, 29.74, 28.71, 28.42, 28.10, 27.16, 27.08, 26.92. FTIR (NaCl, cm^{-1}): 3373.98, 2973.07, 2929.83, 2858.42, 2095.99, 1693.88, 1468.40, 1415.38, 1390.47, 1365.19, 1250.54, 1166.69, 968.23, 884.04, 771.85, 672.26. GPC (THF): M_n = 4.4 kDa; M_w = 7.1 kDa; PDI = 1.54.



Clicked Cyclic Polymer (**C-13**). An oven-dried two-liter two-neck round bottom flask equipped with a stir bar and reflux condenser was charged, under argon, with dry DMF (1.12 L) and N,N,N′,N″,N″-pentamethyldiethylenetriamine (PMDETA, 0.4527g, 2.61 mmol, 20 eq). This solution was sparged vigorously with argon for 30 minutes, and copper(I) bromide (0.3747 g, 2.61 mmol, 20 eq) was added. Sparging was continued for 10 minutes, and then the reservoir was heated to 90 °C. To a separate flame dried flask was added linear diazide homotelechelic polymer **L-12** (0.5000 g, 0.1306 mmol, 1 eq) and 1,4-diethynylbenzene **14** (17.3 mg, 0.1375 mmol, 1.04 eq), and these compounds were dissolved in dry DMF (23.8 ml). This solution was sparged with argon for 20 minutes, then transferred to a 25 ml syringe. The polymer/dialkyne mixture was added via syringe pump to the reservoir of copper/PMDETA/DMF at a rate of 0.3 ml per hour. Once the addition was complete, the reaction was allowed to stir for an additional 2 hours at elevated temperature. The DMF was removed via reduced pressure distillation, and the resulting residue was dissolved in ether (20 ml) and partitioned with water (100 ml). The aqueous layer was further extracted with fresh ether (3 x 20 ml), and the combined organic layers were washed with fresh water (2 x 25 ml). The organic layer was dried ($MgSO_4$), filtered, and evaporated to dryness. The resulting residue was purified by flash chromatography (SiO_2: eluting in a gradient from hexanes, to 25% ether in hexanes, to 50% ether in hexanes, to pure ether) to afford a mixture of linear and cyclic polymer (94.1 mg). This crude polymer residue was redissolved in dry DMF (5.0 ml), and PMDETA (20.4 mg, 0.1176 mmol, 5 eq) and azide-functionalized beads (104 mg, 0.235 mmol azide, 10 eq) were added. The solution was sparged for 15 minutes, and copper(I) bromide (16.9 mg, 0.1176 mmol, 5 eq) was added. The mixture was heated to 90 °C for 6 h with very gentle stirring, and, after this time, alkyne-functionalized beads (235 mg, 0.235 mmol alkyne, 10 eq) were added. Heating and gentle stirring were continued for another 6 h, and the reaction was cooled and filtered. The solution was evaporated to dryness under reduced pressure, and the resulting residue was purified by flash chromatography (SiO_2: eluting in a gradient of 1:1 hexanes to ether, to pure ether) afford pure cyclic polymer **C-13** (80.0 mg, 16% yield) as a colorless oil. ^{1}H NMR (600 MHz, $CDCl_3$): δ

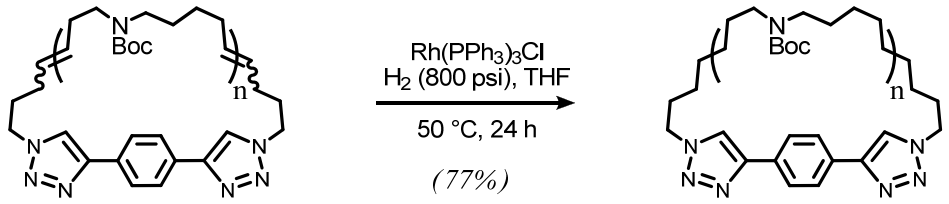
7.88 (s, 0.2H), 7.78 (s, 0.1H), 5.36 (br m, 2H), 4.37 (br s, 0.2H), 3.12 (br m, 4H), 2.17 (m, 2H), 1.96 (m, 2H), 1.42 (br m, 2H), 1.41 (s, 9H), 1.29 (m, 2H). ^{13}C NMR (126 MHz, $CDCl_3$): δ 155.68, 155.66, 147.49, 132.30, 131.72, 130.40, 129.87, 129.15, 128.26, 127.24, 126.56, 126.23, 119.80, 79.17, 79.13, 50.49, 49.87, 47.21, 46.95, 32.55, 31.73, 30.49, 30.18, 29.85, 29.48, 28.81, 28.66, 28.50, 28.38, 28.03, 27.17, 27.11, 27.00, 26.87. FTIR (NaCl, cm^{-1}): 2973.04, 2929.76, 2858.00, 1693.68, 1468.24, 1415.67, 1390.40, 1365.27, 1301.11, 1250.58, 1167.26, 968.89, 883.92, 772.01, 733.43. GPC (THF): M_n = 4.4 kDa; 6.3 Da; PDI = 1.45.



Doubly-Clicked Linear Polymer (**L-15**). To a flame-dried flask equipped with a stir bar and under argon atmosphere was added linear diazide homotelechelic polymer **L-12** (0.100 g, 26.12 μmol, 1 eq), 1,4-diethynylbenzene **14** (0.330 g, 2.6 mmol, 100 eq), PMDETA (23 mg, 0.1306 mmol, 5 eq), and dry DMF (26 ml). This solution was sparged for 15 minutes, and copper(I) bromide (19 mg, 0.1306 mmol, 5 eq) was added. The solution was heated to 50 °C for 4h, then cooled to room temperature. The product was mixed with ether (50 ml) and partitioned with water (100 ml). The aqueous layer was extracted with fresh ether (2 x 50 ml), and the combined organic layer was washed with fresh water (2 x 25 ml). The organic layer was dried ($MgSO_4$), filtered, and evaporated under reduced pressure. This crude mixture was purified by flash chromatography (SiO_2: eluting in a gradient from 1:1 hexanes to ether, to pure ether) to afford the doubly-clicked linear polymer **L-15** as a pale yellow oil (50.9 mg, 48% yield). ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.76 (d + s, J = 8.4 Hz, 0.22H), 7.51 (d, J = 8.2 Hz, 0.15 H), 5.34 (m, 2H), 4.36 (br s, 0.15H), 3.10 (br m + s, 4H), 2.15 (br m, 2H), 1.95 (br m, 2H), 1.45 (m, 2H), 1.41 (s, 9H), 1.27 (m, 2H). ^{13}C NMR (126 MHz, $CDCl_3$): δ 155.69, 155.67, 132.79, 132.32, 131.74, 131.28, 130.41, 129.90, 129.16, 128.20, 127.24, 125.64, 121.81, 120.07, 83.66, 79.18, 79.14, 78.07, 50.54, 49.92, 47.20, 46.95, 32.59, 31.71, 30.15, 29.88, 29.48, 28.68, 28.40, 28.05, 27.19, 27.13, 27.02, 26.89. FTIR (NaCl, cm^{-1}): 3301.80, 3230.47, 2973.68, 2930.41, 2858.54, 2247.99, 1693.99, 1469.67, 1416.84, 1390.93, 1365.54, 1250.77, 1166.70, 969.14, 923.02, 884.01, 772.35, 733.16, 672.20, 646.20. GPC (THF): M_n = 4.4 kDa; M_w = 7.1 kDa; PDI = 1.63.

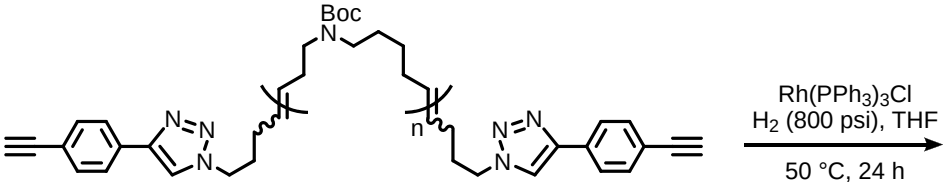
General Hydrogenation Protocol. Polymer was added to a vial and dissolved in tetrahydrofuran (THF, 10 ml). To this mixture was added Wilkinson's catalyst ($Rh(PPh_3)_3Cl$) (1 mol %), and the the vial was sealed inside a stainless-steel high-pressure hydrogenation bomb. The bomb was subjected to three pressurization/release cycles (up to 400 psi H_2 per cycle), then pressurized to 800 psi H_2. The bomb was placed in a oil bath set to 50 °C for 24 h. After the reaction time, the oil bath was removed, and the pressure released. The solvent was removed under reduced pressure, and the resulting residue slowly dripped into a reservoir of hexanes (50

ml). Once the solution had settled, the solids were removed via filtration, and the solvent again evaporated. The residue was purified by flash chromatography (SiO_2: eluting a gradient from pure hexanes, to 25% ether in hexanes, to 50% ether in hexanes, to 75% ether in hexanes, to pure ether) to give the hydrogenated polymer as a clear oil.

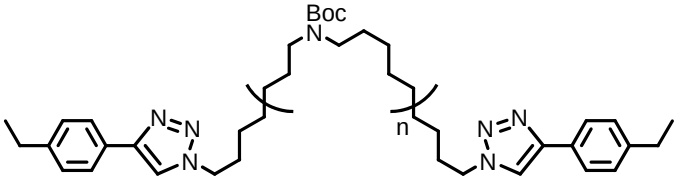


C-13 **C-16**

Saturated Cyclic Product (**C-16**). A portion of the cyclic polymer **C-13** (48.2 mg, 12.1 μmol, 1 eq) and Wilkinson's catalyst (2.0 mg, 2.07 μmol, 1 mol % relative to double bonds) were subjected to standard hydrogenation conditions and purification protocols to produce the saturated derivative **C-16** as a clear oil (37.6 mg, 77% yield). ^{1}H NMR (600 MHz, $CDCl_3$): δ 7.88 (s, 0.2H), 7.78 (s, 0.1H), 4.39 (br s, 0.2H), 3.11 (br s, 4H), 1.94 (m, 0.2H), 1.46 (br s, 4H), 1.42 (s, 9H), 1.35 (br s, 0.8H), 1.25 (m, 8H). ^{13}C NMR (126 MHz, $CDCl_3$): δ 155.81, 147.56, 130.60, 126.26, 119.66, 79.08, 79.05, 50.65, 47.20, 30.52, 29.90, 29.80, 29.65, 29.47, 28.86, 28.71, 28.54, 27.13, 27.08, 26.95, 26.69.



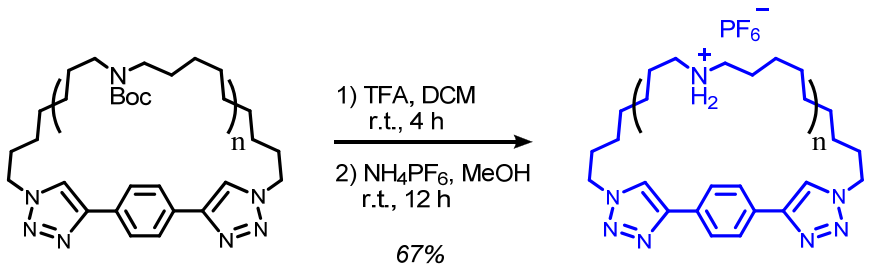
L-15



L-18a

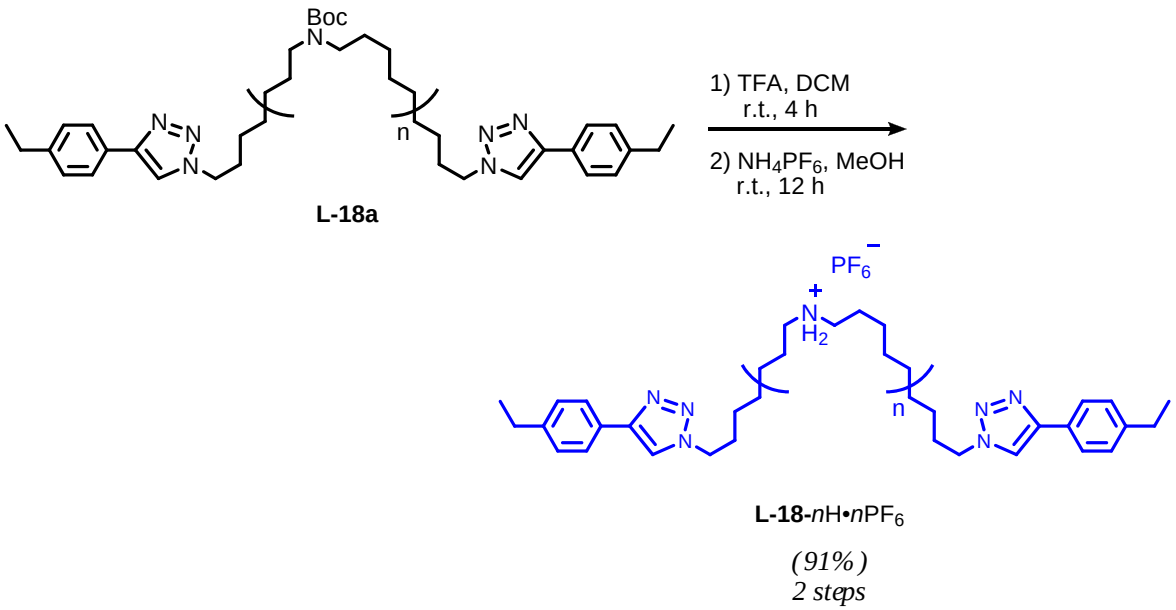
Saturated Doubly-Clicked Linear Polymer (**L-18a**) A portion of the linear doubly-clicked polymer **L-15** (49.9 mg, 12.5 μmol, 1 eq) and Wilkinson's catalyst (2.4 mg, 2.57 μmol, 1 mol % relative to double bonds) were subjected to standard hydrogenation conditions and purification protocols to produce the saturated derivative **L-18a** as a clear oil (29.2 mg, 58% yield). ^{1}H NMR (600 MHz, $CDCl_3$): δ 7.72 (d, J = 8.1 Hz, 0.15H), 7.68 (s, 0.08H), 7.23 (d, J = 8.2 Hz, 0.15H), 4.36 (t, J = 7.2Hz, 0.15H), 3.10 (br m, 4H), 2.65 (q, J = 7.62 Hz, 0.15H), 1.92 (m, 0.15H), 1.46 (m, 4H), 1.42 (s, 9H), 1.23 (br m, 8H).

General Deprotection and Anion Metathesis Protocol. A vial was charged with a stir bar, saturated polymer, and DCM (10 ml). Trifluoroacetic acid (15 eq) was added, and the solution allowed to stir for 4 h. The solvent and TFA were removed *in vacuo*, and the deprotected TFA-ammonium polymer adduct dissolved in methanol (10 ml). Ammonium hexafluorophosphate (10 eq) was added, and the solution allowed to stir for 12 h. The solvent was removed under reduced pressure, and the solid residue was mixed with water (10 ml). The water was decanted, and the remaining solid washed with fresh water (2 x 10 ml) to afford the desired polyammonium hexafluorophosphate polymer as a white solid.

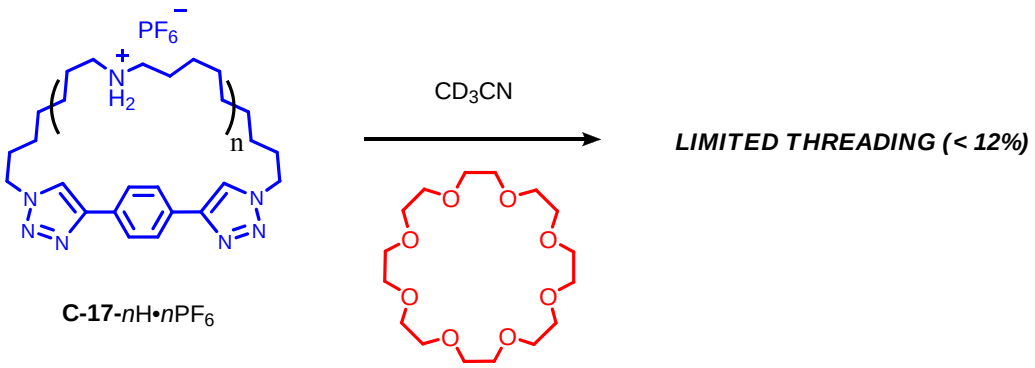


C-16 **C-17-*n*H•*n*PF$_6$**

Polyammonium Hexafluorophosphate Cyclic Polymer (**C-17**-*n*H·*n*PF$_6$). Standard deprotection and anion metathesis conditions were used. Hydrogenated cyclic polymer **C-16** (11.8 mg, 8.04 μmol, 1 eq) was dissolved in DCM, and TFA was added (150 μl, 15 eq per boc). The reaction was allowed to stir for 4 h, then pumped to dryness. Methanol and ammonium hexafluorophosphate (210 mg, 1.29 mmol, 10 eq per N) were added. The solution was stirred for 12 h, the methanol was removed, and the standard extraction protocol was performed to afford the cyclic polyammonium hexafluorophosphate polymer **C-17**-*n*H·*n*PF$_6$ as a white solid (25.3 mg, 67% over two steps). ^{1}H NMR (600 MHz, CD_3CN): δ 8.13 (s, 0.1H), 7.91 (s, 0.2H), 6.47 (br s, 2H), 4.41 (s, 0.2H), 2.95 (s, 4H), 1.62 (s, 4H), 1.32 (br s, 8H). ^{13}C NMR (126 MHz, CD_3CN): δ 126.95, 121.91, 49.24, 49.03, 30.05, 29.74, 29.46, 27.04, 26.90, 26.66, 26.39, 26.34. 2D-DOSY NMR $\log_{10}$(diffusion) = -8.83.

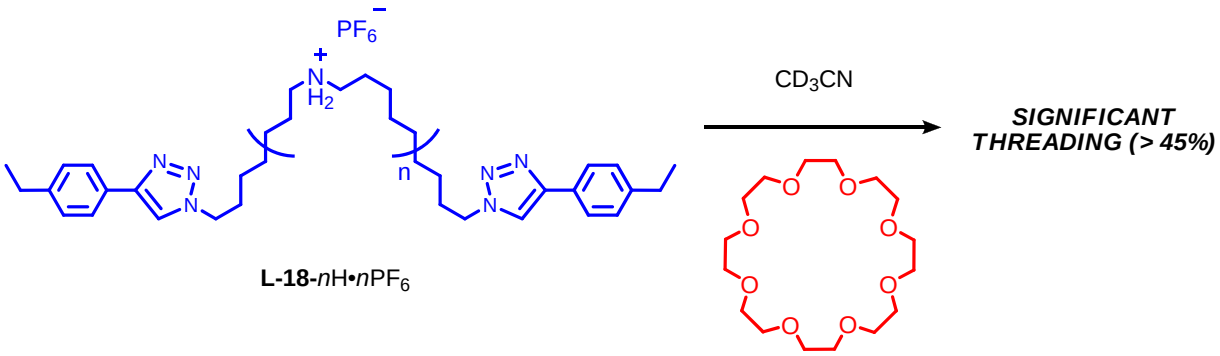


Polyammonium Hexafluorophosphate Doubly-Clicked Linear Polymer (**L-18-***n*H·*n*PF_6). Standard deprotection and anion metathesis conditions were used. Hydrogenated linear doubly-clicked polymer **L-18a** (32.1 mg, 2.86 µmol, 1 eq) was dissolved in DCM, and TFA was added (150 µl). The reaction was allowed to stir for 4 h, then pumped to dryness. Methanol and ammonium hexafluorophosphate (75 mg, 450 µmol, 10 eq per N) were added. The solution was stirred for 12 h, the methanol was removed, and the standard extraction protocol was performed to afford the linear doubly-clicked polyammonium hexafluorophosphate polymer **L-18-***n*H·*n*PF_6 as a white solid (13.6 mg, 98% over two steps). ^{1}H NMR (600 MHz, CD_3CN): δ 8.04 (s, 0.1H), 7.74 (d, J = 8.2 Hz, 0.2H), 7.30 (d, J = 8.2 Hz, 0.2H), 6.37 (br s, 2H), 4.39 (m, 0.2H), 2.95 (br m, 4H), 2.67 (q, J = 7.6 Hz, 0.2H), 1.62 (br m, 4H), 1.32 (br m, 8H), 1.24 (t, J = 7.61 Hz, 0.35H).

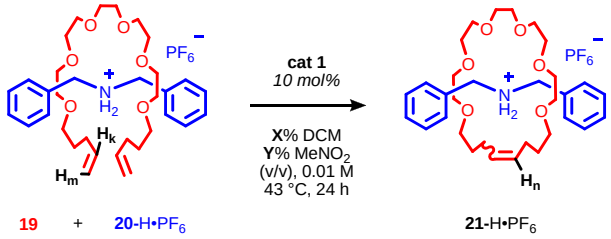


24-Crown-8 Ether Threading of Cyclic Polymer C-17-*n*H·*n*PF_6. A sample of **C-17-***n*H·*n*PF_6 (1.0 mg) was dissolved in acetonitrile (0.75 ml, 5 mM ammonium concentration) and mixed with 24-crown-8 ether (24C8, 0.5 eq per ammonium). After analysis, additional 24C8 (total of 2 eq per ammonium) was introduced, and the solution analyzed again. Threaded Peaks (0.5 eq 24C8): ^{1}H NMR (600 MHz, CD_3CN, 25 °C): δ 3.25-3.00 (br m, 0.02H), 2.96 (br m, 1H);

Threaded percent = (0.02 / 1)*100 = 2%. Threaded Peaks (2.0 eq 24C8): ^{1}H NMR (600 MHz, CD_3CN, 25 °C): δ 3.25-3.00 (br m, 0.12H), 2.96 (br m, 1H).



24-Crown-8 Ether Threading of Hexafluorophosphate Doubly-Clicked Linear Polymer L-18-*n*H·*n*PF$_6$. A sample of **L-18-*n*H·*n*PF$_6$** (1.0 mg) was dissolved in deuterated acetonitrile (0.75 ml, 5 mM ammonium concentration) and mixed with 24-crown-8 ether (24C8, 0.5 eq per ammonium). After analysis, additional 24C8 (total of 2 eq per ammonium) was added, and the solution analyzed again. Threaded Peaks (0.5 eq 24C8): ^{1}H NMR (600 MHz, CD_3CN, 25 °C): δ 3.25-3.00 (br m, 0.28H), 2.96 (br m, 1H); Threading Percent = (0.28 / 1)*100 = 28% Threaded Peaks (2.0 eq 24C8): ^{1}H NMR (600 MHz, CD_3CN, 25 °C): δ 3.25-3.00 (br m, 0.86H), 2.96 (br m, 1H).

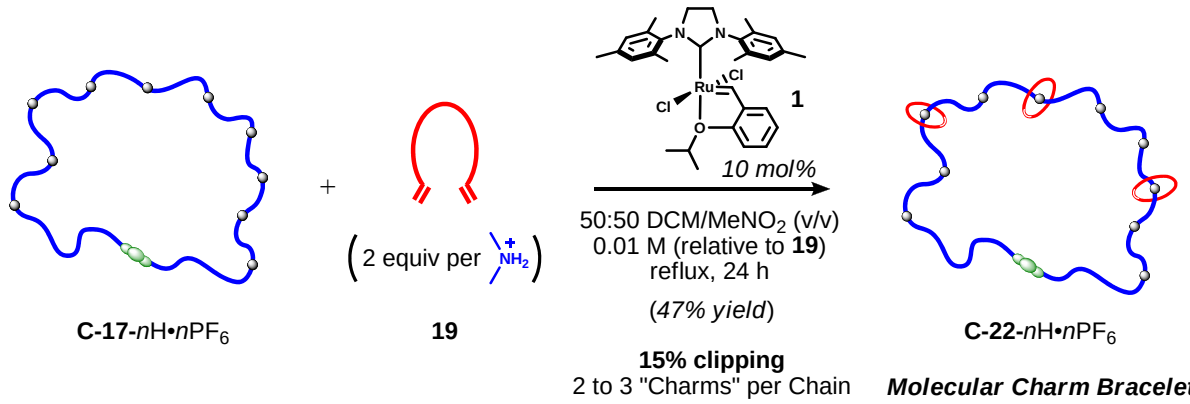


Entry	**X** % DCM	**Y** % $MeNO_2$	Conversion [%] [a]
1	100	0	quant
2	95	5	90
3	90	10	90
4	80	20	85
5	50	50	62
6	25	75	54
7	0	100	30

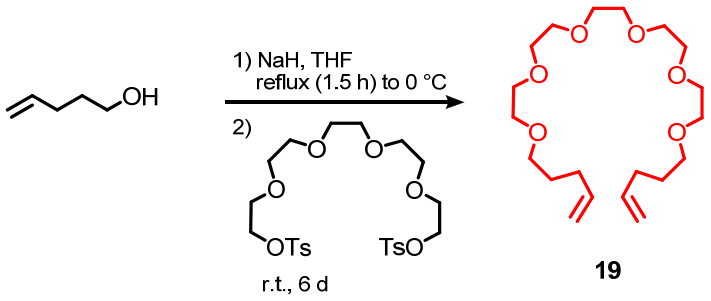
[a] Conversion measured by ^{1}H NMR integration of H_m relative to H_n after 24h.

Procedure for "Clipped" Pseudorotaxane (**21**-H·PF$_6$). ***ENTRY 5:*** Dibenzylammonium hexafluorophosphate template **20**-H·PF$_6$ (10 mg, 29.15 µmol, 1 eq) and diolefin crown ether-type species **19** (10.9 mg, 29.15 µmol, 1 eq) were added to a flame dried vial equipped with a stir bar and under an argon atmosphere, then dissolved in solvent (50% DCM, 50% Nitromethane, 2.9 ml total volume, 0.01 M relative to **19**). The mixture was degassed via the standard freeze-

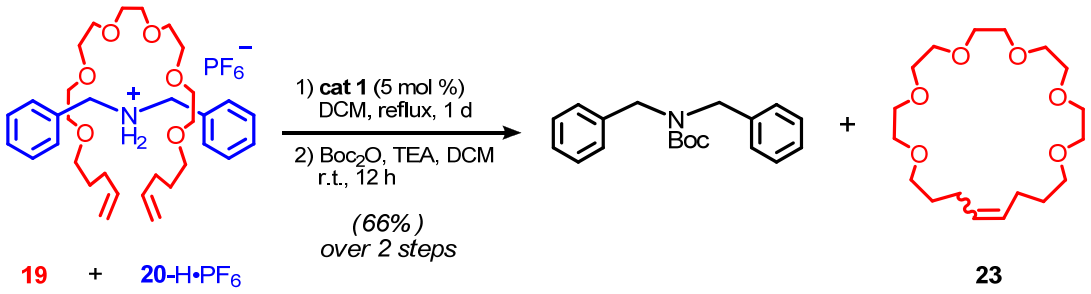
pump-thaw protocol, backfilling with argon. On the third freeze, ruthenium metathesis catalyst $(H_2IMes)(Cl)_2RuCH(o\text{-}OiPrC_6H_4)$ **1** (1.9 mg, 2.9 μmol, 10 mol %). The headspace was evacuated, and the reaction subjected to one final freeze-pump-thaw cycle. The solution was heated to 43 °C for 24 h. The reaction was cooled to r.t., and ethyl vinyl ether (0.2 ml) was injected and allowed to stir for 30 minutes. The solvents were removed under reduced pressure, and the conversion of the crude product was analyzed with no further purification. Example ^{1}H integration for determination of conversion percent (Entry 5): ^{1}H (500 MHz, $CDCl_3$): δ 5.85-5.72 (m, 1.74 H, H_k), 5.40-5.25 (m, 3.21 H, H_n), 5.03-4.88 (m, 4.00 H, H_m). *Conversion %* = 3.21 / (3.21 + (4.00 / 2)) = ~62%



Molecular "Charm Bracelet" (**C-22-***n*H·*n*PF_6). To a flame dried vial equipped with a stir bar and under argon was added a portion of **C-17-***n*H·*n*PF_6 (5.0 mg, 1.1 μmol, 1 eq) and diolefin crown ether-type species **19** (12.7 mg, 33.9 μmol, 32 eq, 2 eq per ammonium). To this mixture was added nitromethane (1.7 ml), followed by DCM (1.7 ml, total solvent concentration 0.01 M relative to **19**). The solution was degassed via sparging with argon for 15 minutes. Catalyst $(H_2IMes)(Cl)_2RuCH(o\text{-}OiPrC_6H_4)$ **1** (2.2 mg, 3.39 μmol, 10 mol% relative to **19**) was added, and the headspace quickly evacuated. Another freeze-pump-thaw cycle was completed, after which the reaction was heated to 43 °C for 24 h. The solution was cooled to r.t., and quenched via addition of excess ethyl vinyl ether (0.5 ml). The solvent was removed under reduced pressure, and the resulting solid was dissolved in a minimum of acetonitrile and added to a stirring reservoir of DCM (30 ml). The solvent was decanted to afford the molecular "charm bracelet" interlocked complex **C-22-***n*H·*n*PF_6 as a white solid (2.7 mg, 47% yield, 15% clipping, 2 to 3 charms per polymer). ^{1}H NMR (600 MHz, CD_3CN): δ 8.13 (br s, 0.6H), 7.92 (s, 0.12H), 6.72 (br s, 1H), 5.90 (br s), 5.58-5.20 (br m, 0.2H), 4.41 (m, 0.14H), 3.68-3.30 (m, 3.6H), 2.96 (m, 4H), 2.30 (m, 0.47 H), 1.63 (m, 4.8H), 1.33 (m, 12H). 2D-DOSY NMR for crown and polymer ^{1}H signals: $\log_{10}$(diffusion) = -8.85

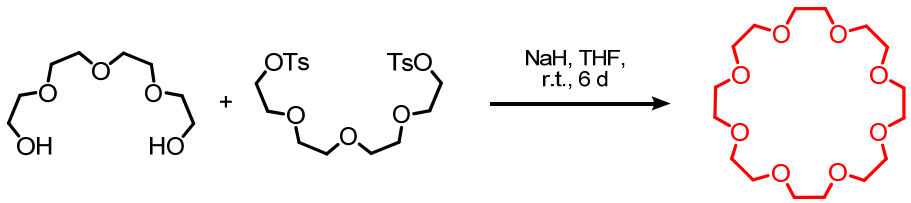


Synthesis of Clipping Crown (**19**). To a flame dried flask equipped with a reflux condenser and stir bar and under an argon atmosphere was added sodium hydride (40 g, 1.0 moles, 5 eq, 60% dispersion in mineral oil) and dry THF (1 L), followed by 4-penten-1-ol (19.03 g, 221 mmol, 2.2 eq) dissolved in dry THF (110 ml). The solution was heated to reflux for 1.5 h, then cooled to 0 °C. The reflux condenser was replaced by an addition funnel charged with pentaethylene glycol ditosylate (54.9 g, 100.4 mmol, 1 eq) dissolved in dry THF (110 ml), and this solution was slowly added over 1 h. The solution was allowed to stir at r.t. under an Ar atmosphere for 6 d, then quenched by slow addition of methanol. The volatiles were removed by rotary evaporation, and the oil dissolved in DCM (500 ml) and partitioned with water (500 ml) in a separatory funnel. The aqueous layer was further washed with ether (2 x 200 ml), and the combined organic layers were dried ($MgSO_4$), filtered, and evaporated to dryness to give an orange oil. The crude product was purified by flash chromatography (SiO_2: eluting in 2:1 hexanes to ethyl acetate) to afford **19** a clear, colorless oil (18.41 g, 49% yield) ^{1}H NMR (500 MHz, $CDCl_3$): δ 5.78 (m, 2H), 4.97 (m, 4H), 3.65-3.50 (m, 20H), 3.44 (t, J = 6.7 Hz, 4H), 2.08 (q, J = 7.2 Hz, 4H), 1.65 (qt, J = 7.1 Hz, 4H). ^{13}C NMR (126 MHz, $CDCl_3$): δ 138.49, 114.88, 70.91, 70.82, 70.80, 70.80, 70.31, 30.44, 28.98. HRMS-FAB (m/z): [M + H] calcd for $C_{20}H_{39}O_6$, 375.2747; found 375.2733.



Pure Ring-Closed Clipping Crown (**23**). A flame dried vial was charged with dibenzylammonium hexafluorophosphate template **20-H·PF$_6$** (202 mg, 587 µmol, 1.1 eq), diolefin polyether fragment **19** (200 mg, 534 µmol, 1 eq), and dry DCM (53.4 ml, 0.01 M). The solution was sparged with argon for 20 min, and catalyst **1** (16.8 mg, 26.7 µmol, 5 mol%) was introduced in one portion. Sparging was continued for 5 min, and the reaction heated to 43 °C for 24h. The solution was cooled to r.t., and quenched with ethyl vinyl ether. Volatiles were removed under reduced pressure, and the resulting residue was mixed with DCM (30 ml),

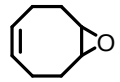
triethylamine (328 µl, 2.35 mmol, 4 eq), and boc-anhydride (270 µl, 1.18 mmol, 2 eq). Reaction was allowed to continue for 12 h at r.t., and the solvent removed via rotary evaporation. The crude orange oil was subjected to flash chromatography (SiO2: eluting in a gradient of 20:1 hexanes to acetone, to 16:1, to 10:1 to 5:1), giving ring-closed product **23** as a clear, pale-yellow oil (0.1227 g, 66% yield over 2 steps). ^{1}H NMR (500 MHz, $CDCl_3$): δ 5.45-5.35 (m, 2H), 3.75-3.55 (m, 20H), 3.48 (m, 4H), 2.15-2.05 (m, 4H), 1.65 (m, 4H). ^{13}C NMR (126 MHz, CD_3CN): δ 130.49, 129.99, 71.03, 70.99, 70.95, 70.88, 70.67, 70.59, 70.41, 29.78, 29.40, 29.02, 23.93. 2D-DOSY NMR $\log_{10}(D)$ = -8.45. HRMS-FAB (m/z): [M + H] calcd for $C_{18}H_{35}O_6$, 347.2434; found 347.2422.



24-Crown-8 Ether

Synthesis of 24-Crown-8 Ether (24C8). 24C8 was prepared according to a literature procedure.[5] A flame dried flask equipped with an addition funnel and stir bar, and under an argon atmosphere, was charged with sodium hydride (24 g, 600 mmol, 24 eq, 60% dispersion in mineral oil) and dry THF (100 ml). To the addition funnel was added a solution of tetraethylene glycol ditosylate (12.94 g, 25.7 mmol, 1 eq) and tetraethylene glycol (5 g, 25.7 mmol, 1 eq) dissolved in dry THF (300 ml), and this was slowly introduced to the reservoir of THF/NaH at r.t. over 2 d. After addition was complete, the solution was allowed to stir for 1 week at r.t. under an argon atmosphere. The brown solution was quenched with water (12 ml), filtered (fritted glass) to remove salts, and evaporated to dryness under reduced pressure. The brown oil was dissolved in refluxing hexanes (1000 ml total, added in 4 portions of 500 ml, 300 ml, 100 ml, and 100ml) and poured through filter paper. The hexanes were removed via rotary evaporation, and the oil dissolved in acetonitrile (500 ml). After concentration to 100 ml of solution volume, the mixture was placed in the freezer overnight, resulting in precipitation of clear, colorless crystals. The crystals were quickly collected by decanting the supernatant, followed by several washings with fresh, cold acetonitrile. The crystals were place under high vacuum to afford 24-crown-8 ether as a clear, colorless oil (1.8069 g, 20% yield). ^{1}H NMR (500 MHz, $CDCl_3$): δ 3.65 (s, 32H). ^{13}C NMR (126 MHz, CD_3CN): δ 71.05. HRMS-FAB (m/z): [M + H] calcd for $C_{16}H_{33}O_8$, 353.2175; found 353.2192.

Reference:
(5) Talanov, V. S.; Bartsch, R. A. *Synth. Commun.* **1999**, *29*, 3555.

^{1}H NMR of: 

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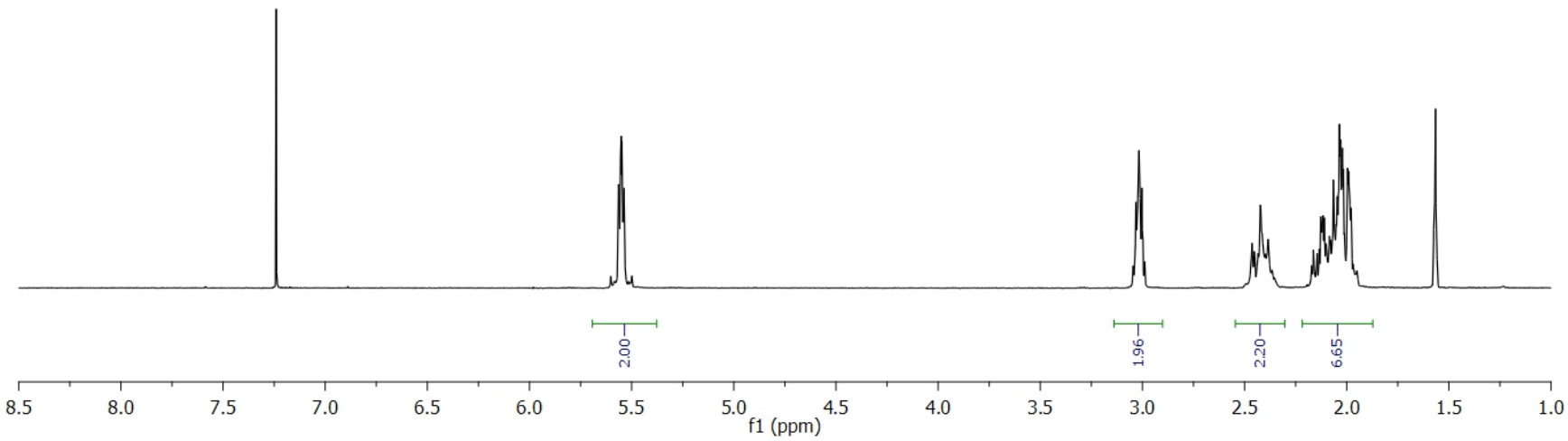
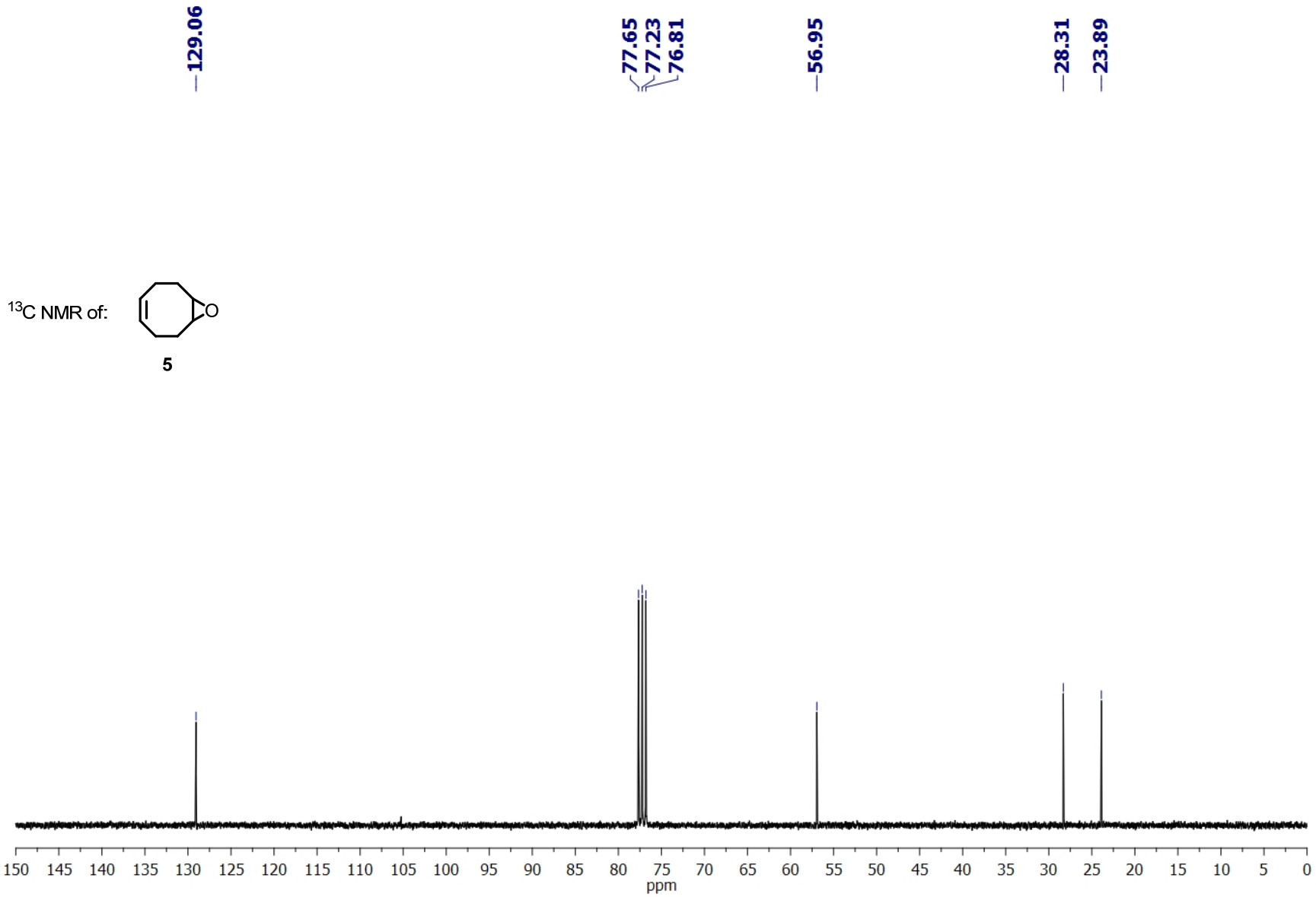
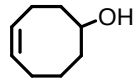
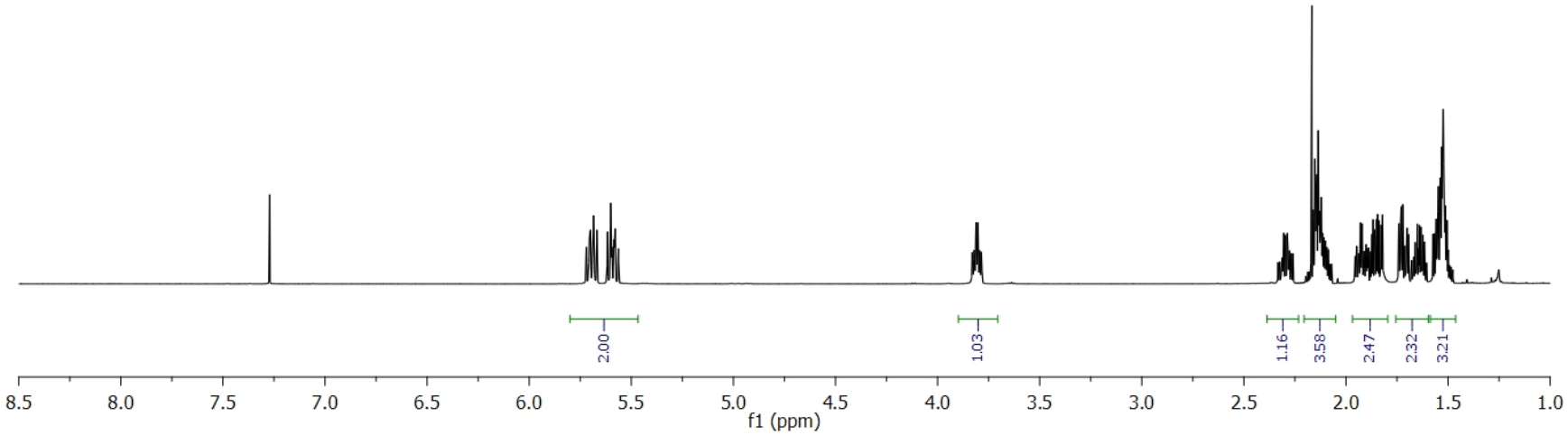



129.06
77.65
77.23
76.81
56.95
28.31
23.89
13C NMR of:
O
5
150 145 140 135 130 125 120 115 110 105 100 95 90 85 80 75 70 65 60 55 50 45 40 35 30 25 20 15 10 5 0
ppm

^{1}H NMR of:

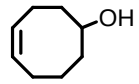

OH

6


2.00
1.03
1.16
3.58
2.47
2.32
3.21
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
f1 (ppm)

130.34
129.73
77.48
77.23
76.98
72.93
37.91
36.47
25.85
25.07
22.98

^{13}C NMR of:



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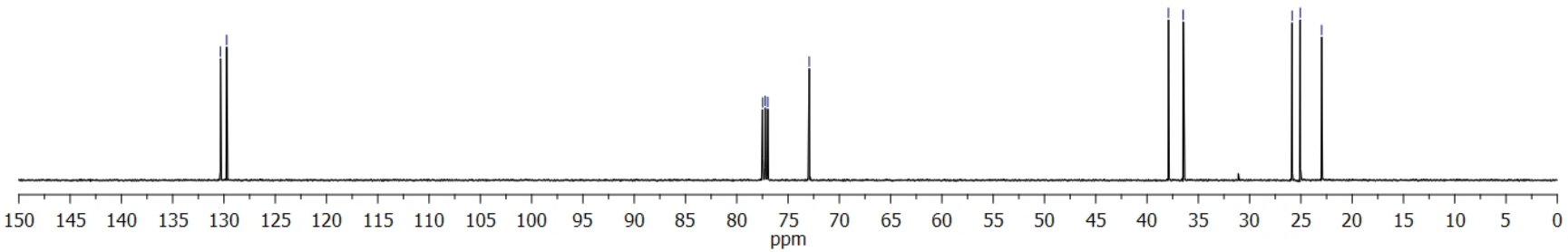
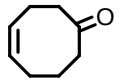


^{1}H NMR of:



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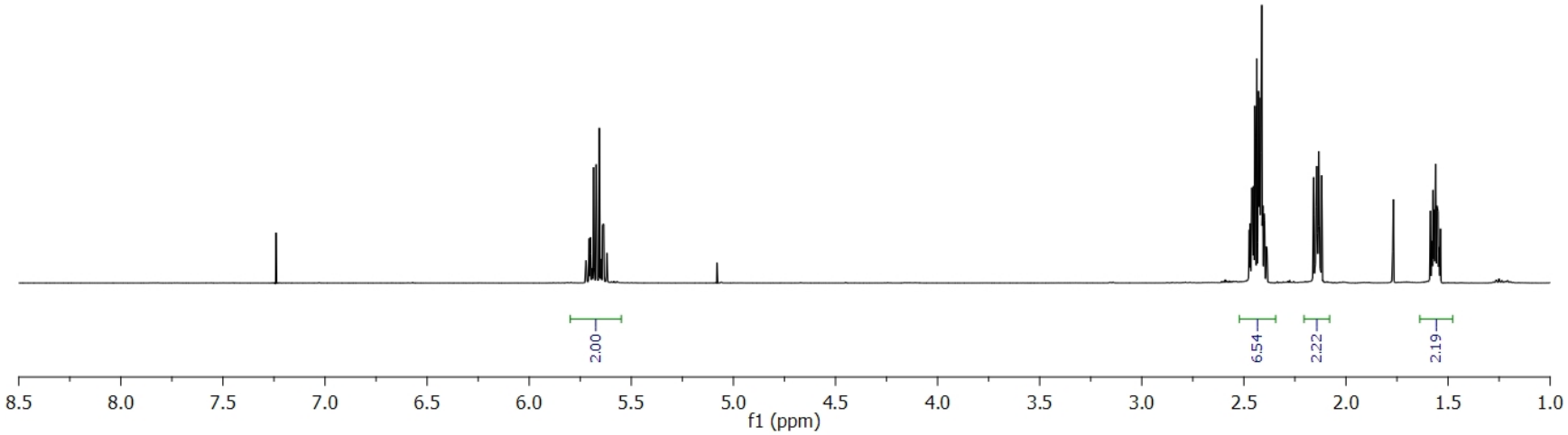

214.91
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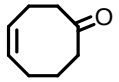
130.41
77.48
77.23
76.98
47.43
40.54
26.50
24.11
22.02

^{13}C NMR of:



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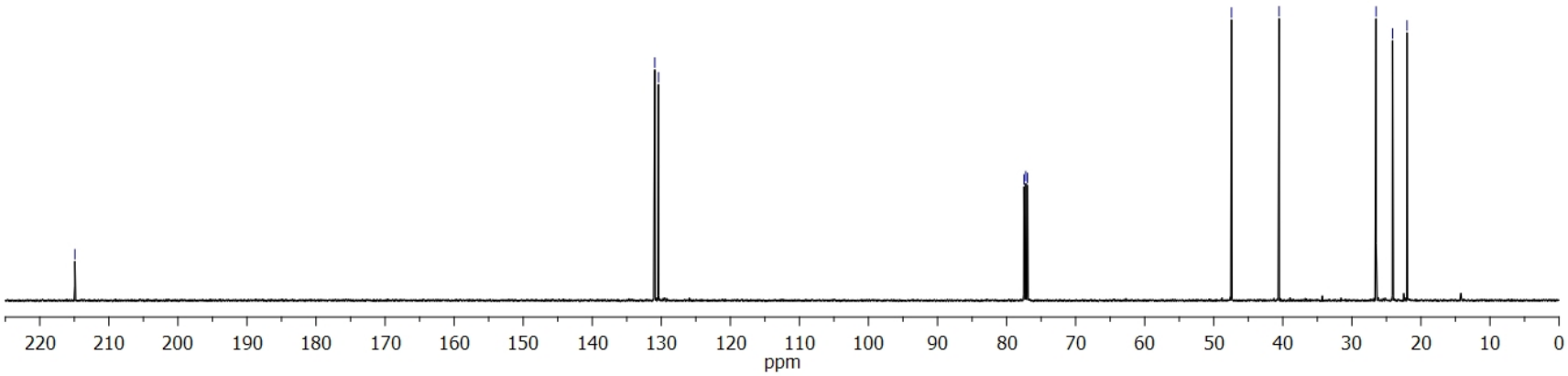

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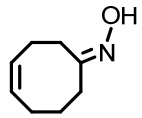
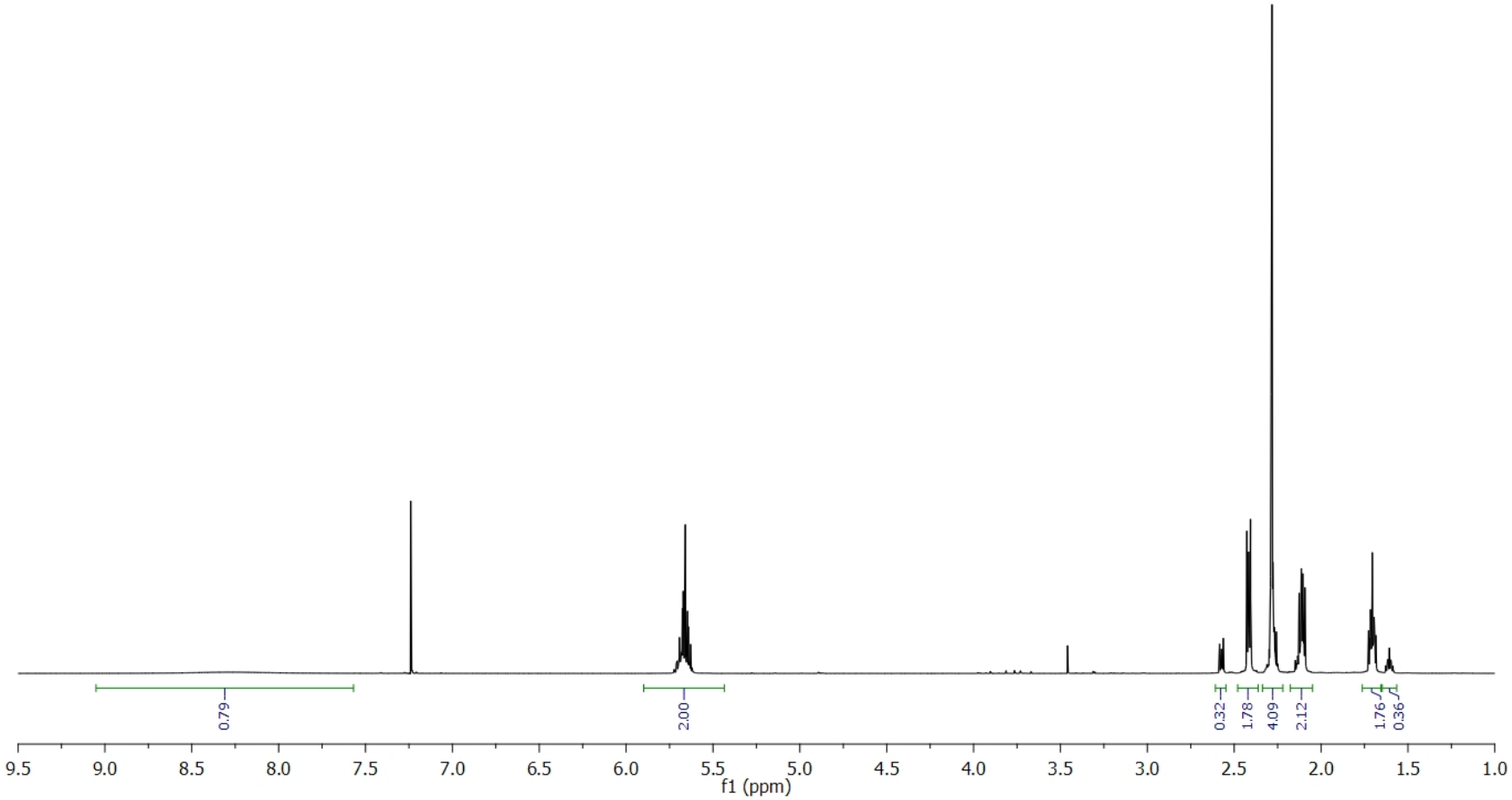

OH
N

8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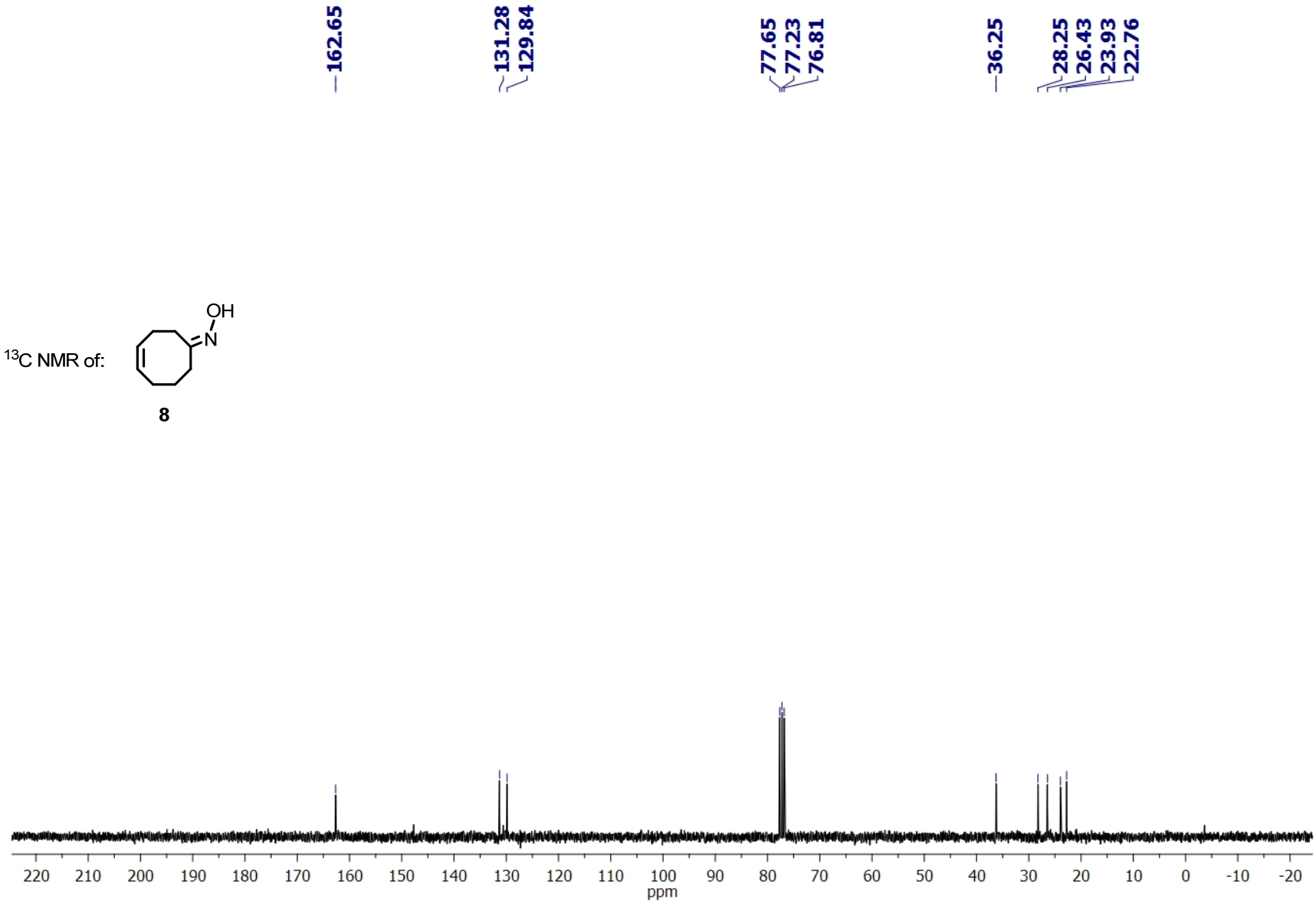
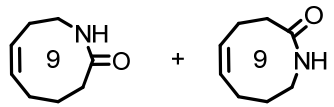
0.32
1.78
4.09
2.12
1.76
0.36
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
f1 (ppm)


162.65
131.28
129.84
77.65
77.23
76.81
36.25
28.25
26.43
23.93
22.76
13C NMR of:
OH
N
8
220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30 20 10 0 -10 -20
ppm

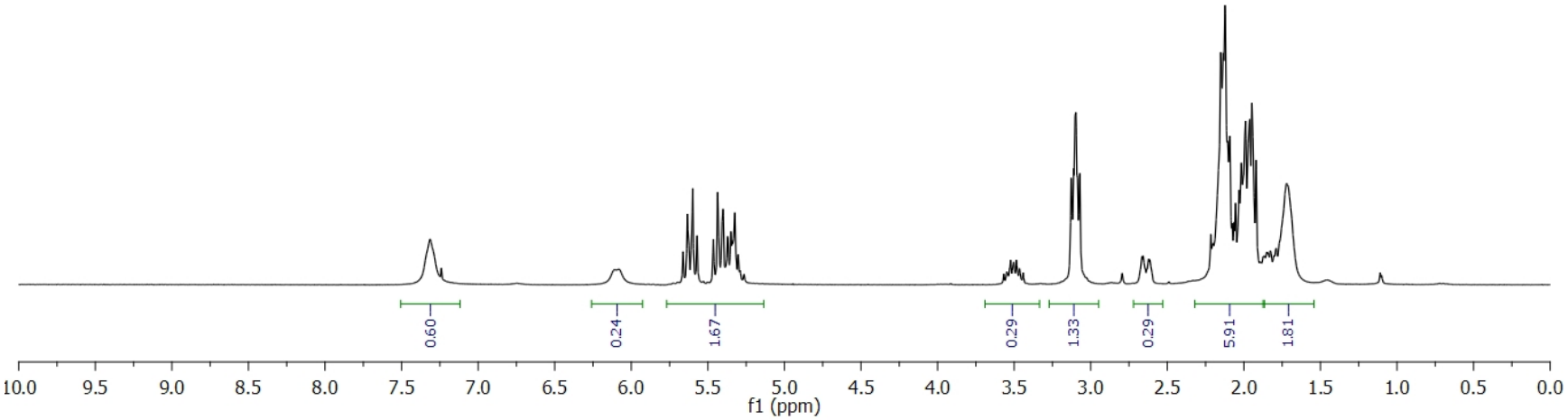
^{1}H NMR of:



9a

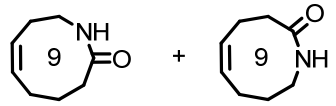
+

9b



178.07
176.88
134.12
131.45
128.82
124.97
77.66
77.23
76.80
42.17
38.89
36.39
29.41
28.86
27.67
26.72
25.55
25.41

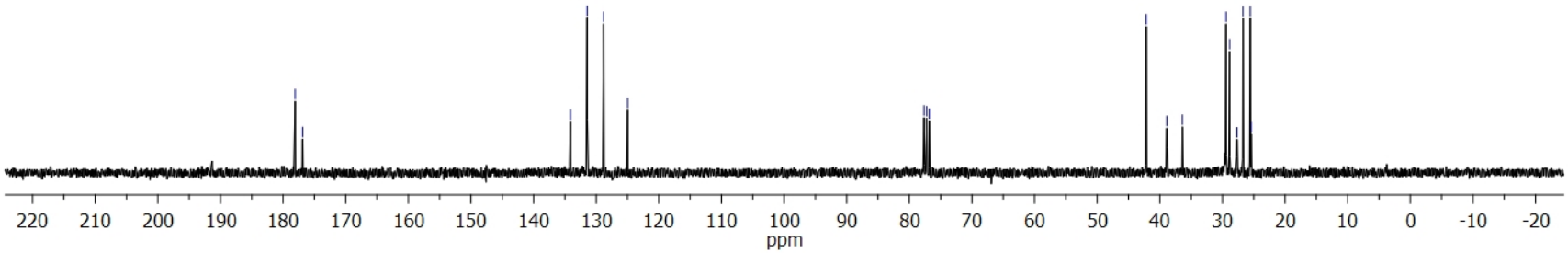
^{13}C NMR of:



9a

+

9b



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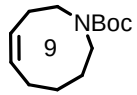
NBoc
9

3

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1.06
1.16
1.04
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2.25
2.23
5.23
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9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
f1 (ppm)

156.09
155.51
131.99
131.37
129.16
128.58
79.23
79.12
77.37
77.16
76.95
48.42
48.26
47.89
47.82
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25.54
25.38
24.29
23.58

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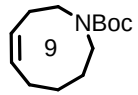

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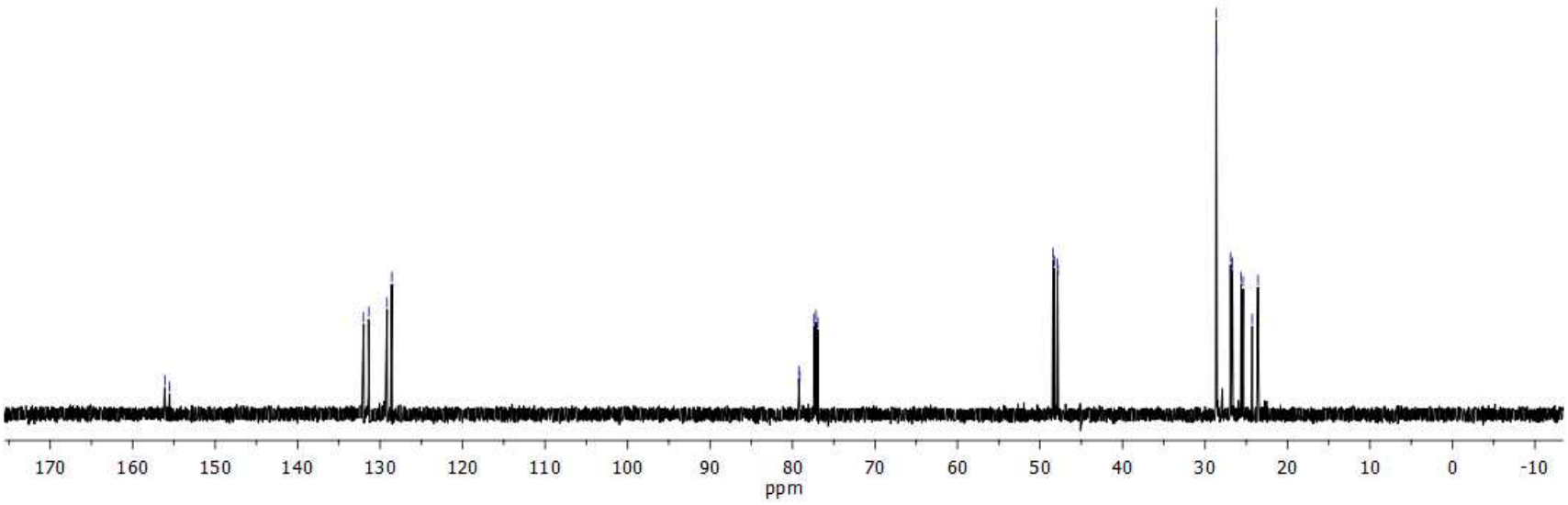

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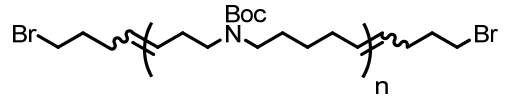
Boc
N
Br
Br
n

L-11

2.06
0.21
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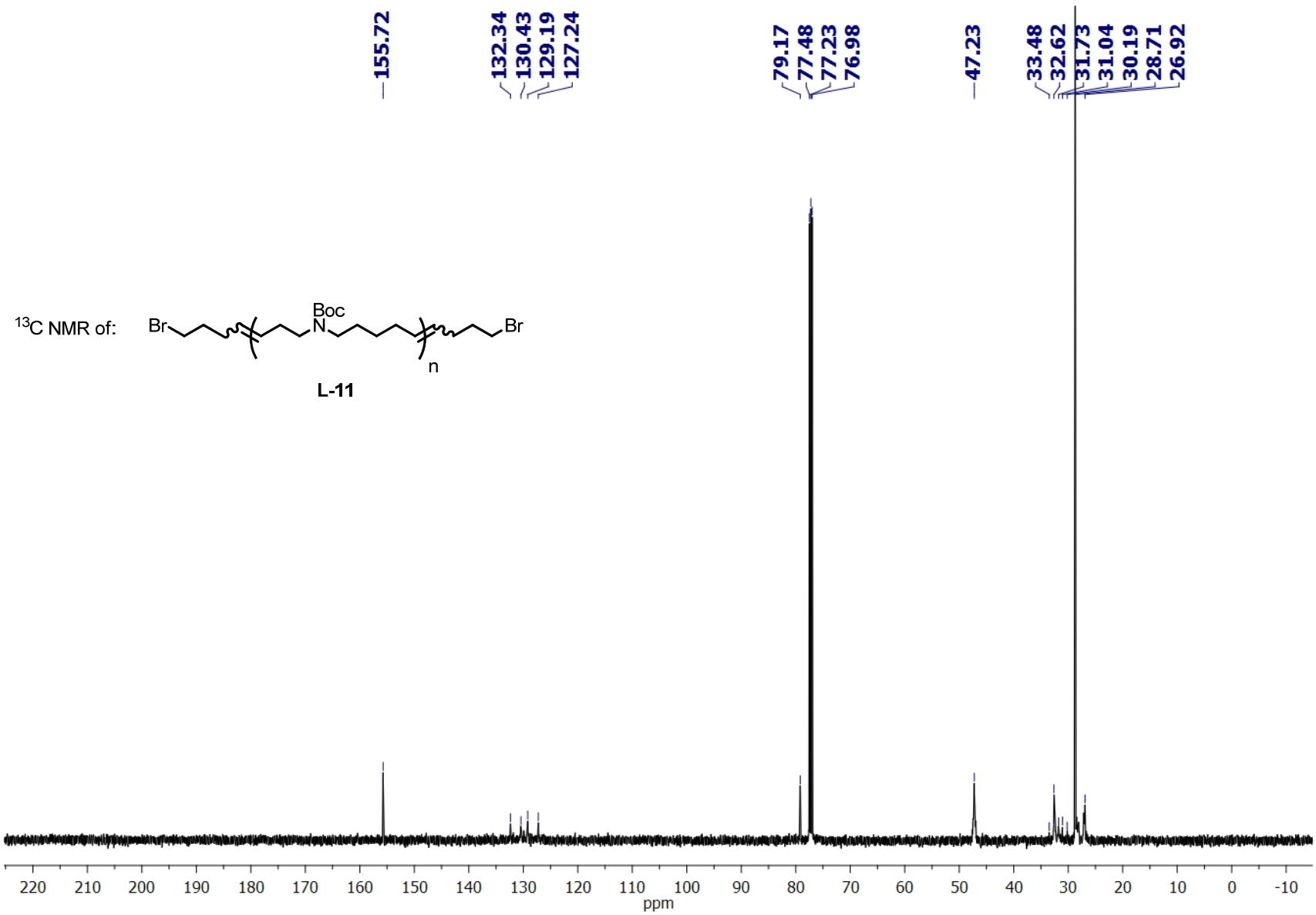
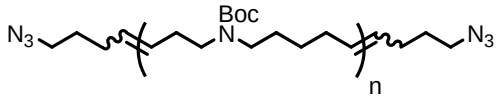
2.06
2.34
2.50
9.02
2.07
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
f1 (ppm)

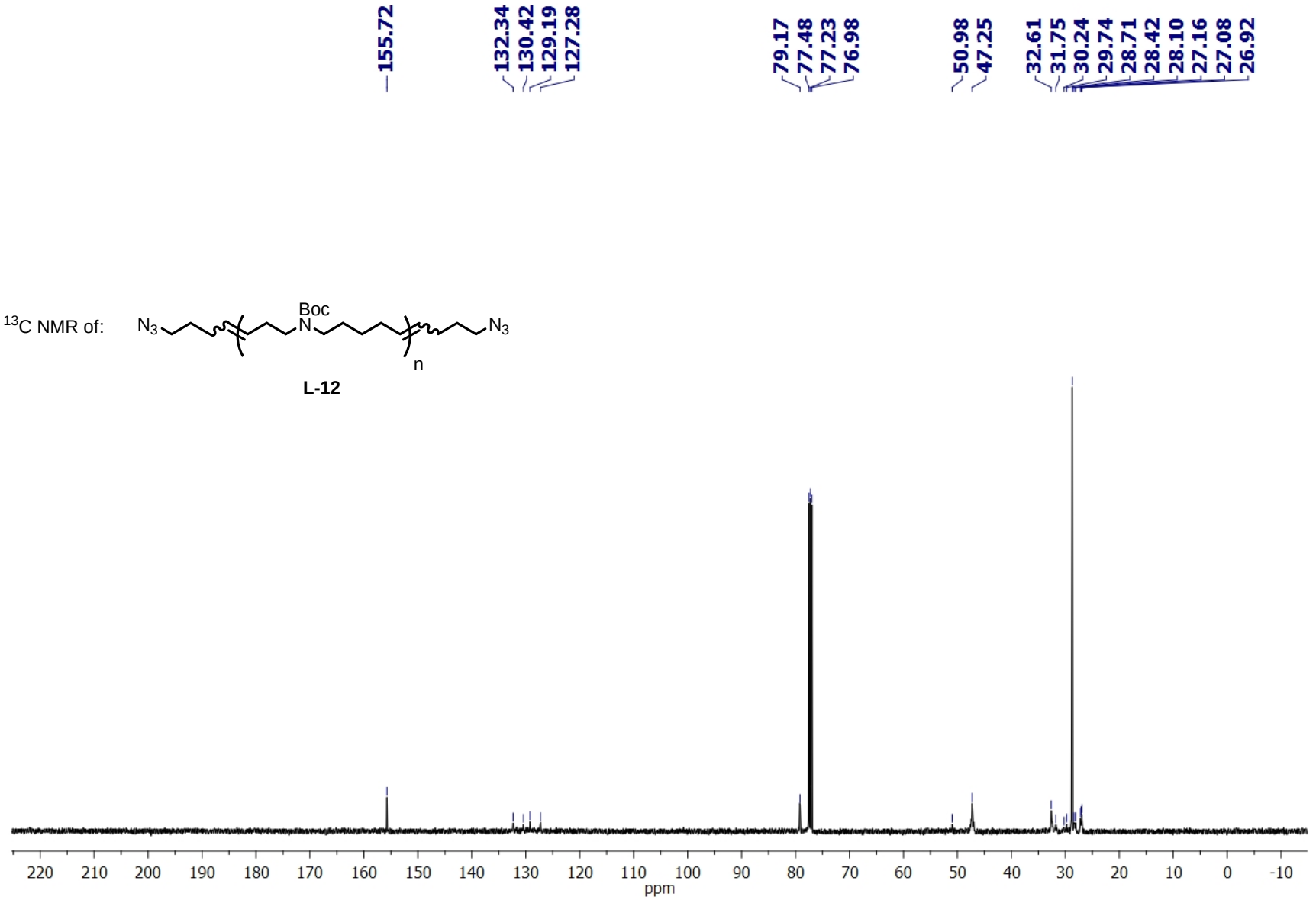

155.72
132.34
130.43
129.19
127.24
79.17
77.48
77.23
76.98
47.23
33.48
32.62
31.73
31.04
30.19
28.71
26.92
13C NMR of:
Br
Boc
N
Br
n
L-11
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
ppm

^{1}H NMR of:

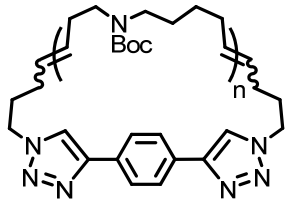

Boc
N
N3
N3
n

L-12

2.07
0.21
4.00
1.92
2.26
2.37
9.05
2.28
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
f1 (ppm)


155.72
132.34
130.42
129.19
127.28
79.17
77.48
77.23
76.98
50.98
47.25
32.61
31.75
30.24
29.74
28.71
28.42
28.10
27.16
27.08
26.92
13C NMR of:
N3
Boc
N
N3
n
L-12
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
ppm

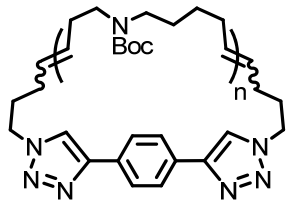
^{1}H NMR of:


N
Boc
n
N
N
N
N
N
N

C-13

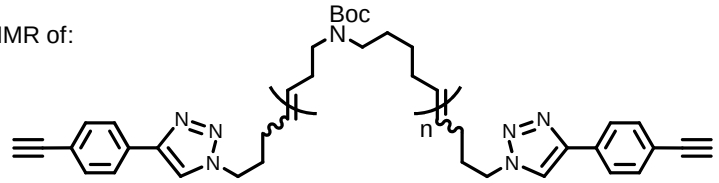
0.21
0.10
2.08
0.21
4.00
1.82
2.46
1.77
9.35
2.01
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
f1 (ppm)

^{13}C NMR of:



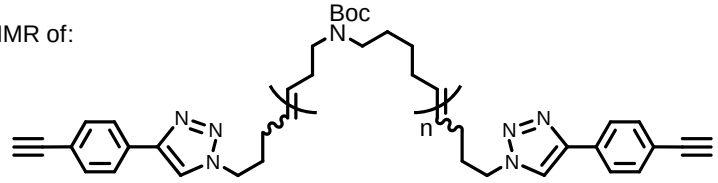
C-13

^{13}C NMR of:



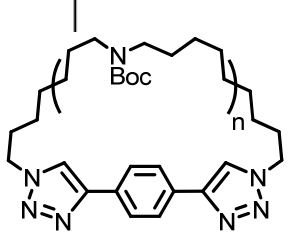
L-15

^{13}C NMR of:



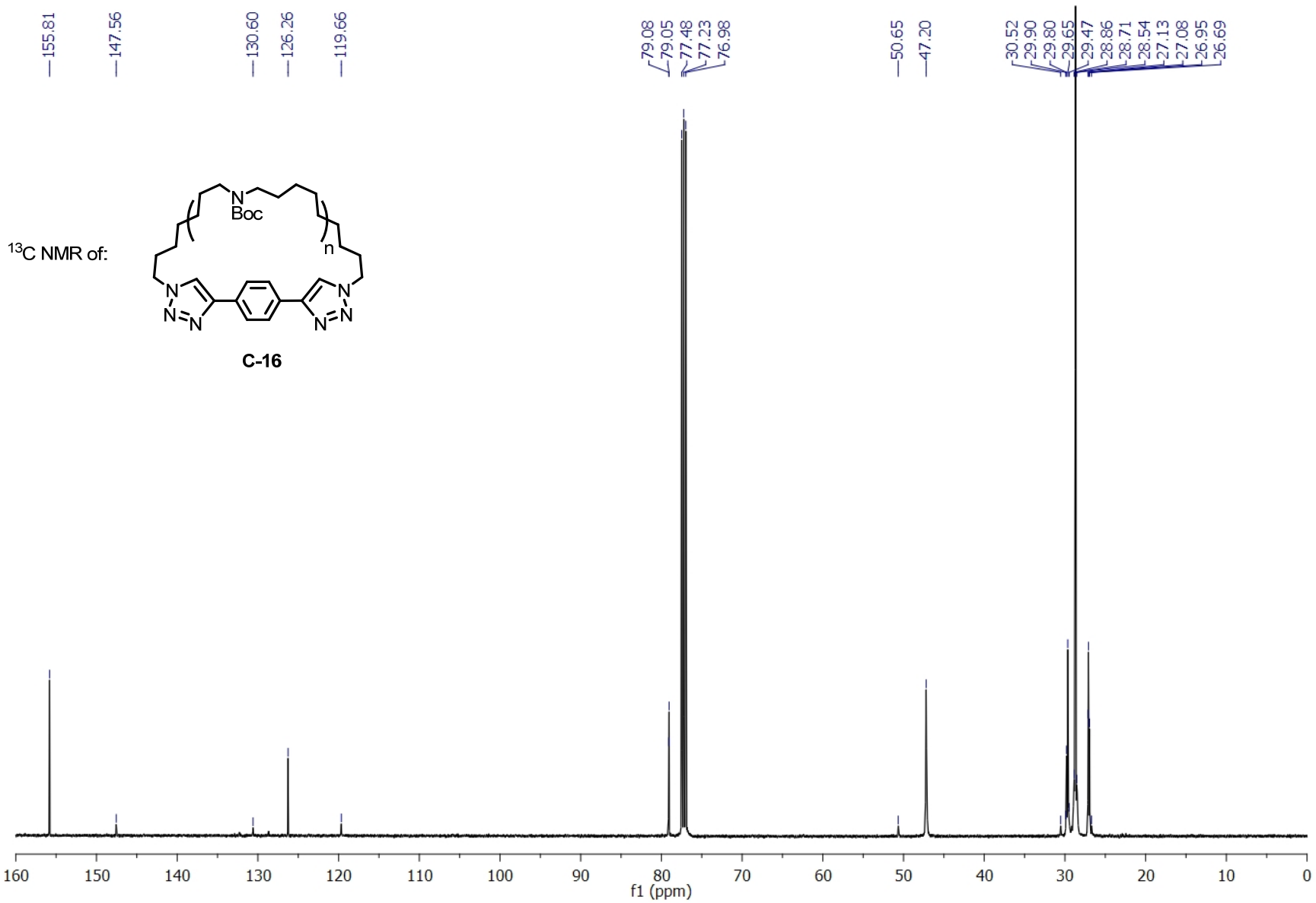
L-15

^{1}H NMR of:

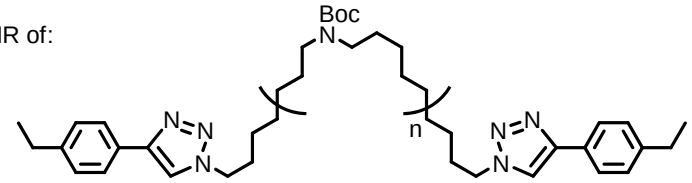

N
Boc
n
N
N
N
N
N

C-16

7.88
7.78
4.39
3.11
1.94
1.46
1.42
1.35
1.25
1.23
0.22
0.12
0.23
4.00
0.30
3.66
8.72
0.80
8.11
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
f1 (ppm)

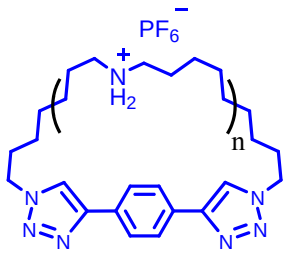

155.81
147.56
130.60
126.26
119.66
79.08
79.05
77.48
77.23
76.98
50.65
47.20
30.52
29.90
29.80
29.65
29.47
28.86
28.71
28.54
27.13
27.08
26.95
26.69
13C NMR of:
N
Boc
n
N
N
N
N
N
C-16
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

^{1}H NMR of:



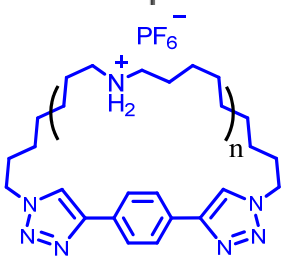
L-18a

^{1}H NMR of:



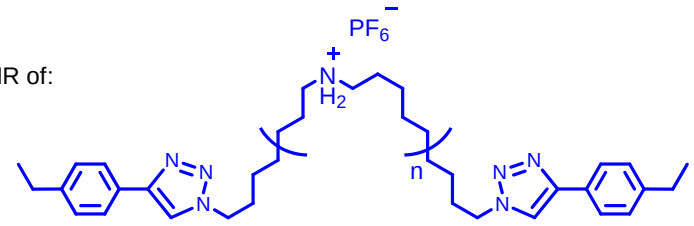
C-17-*n*H•*n*PF$_6$

^{13}C NMR of:



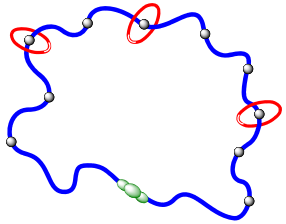
C-17-*n*H•*n*PF$_6$

^{1}H NMR of:



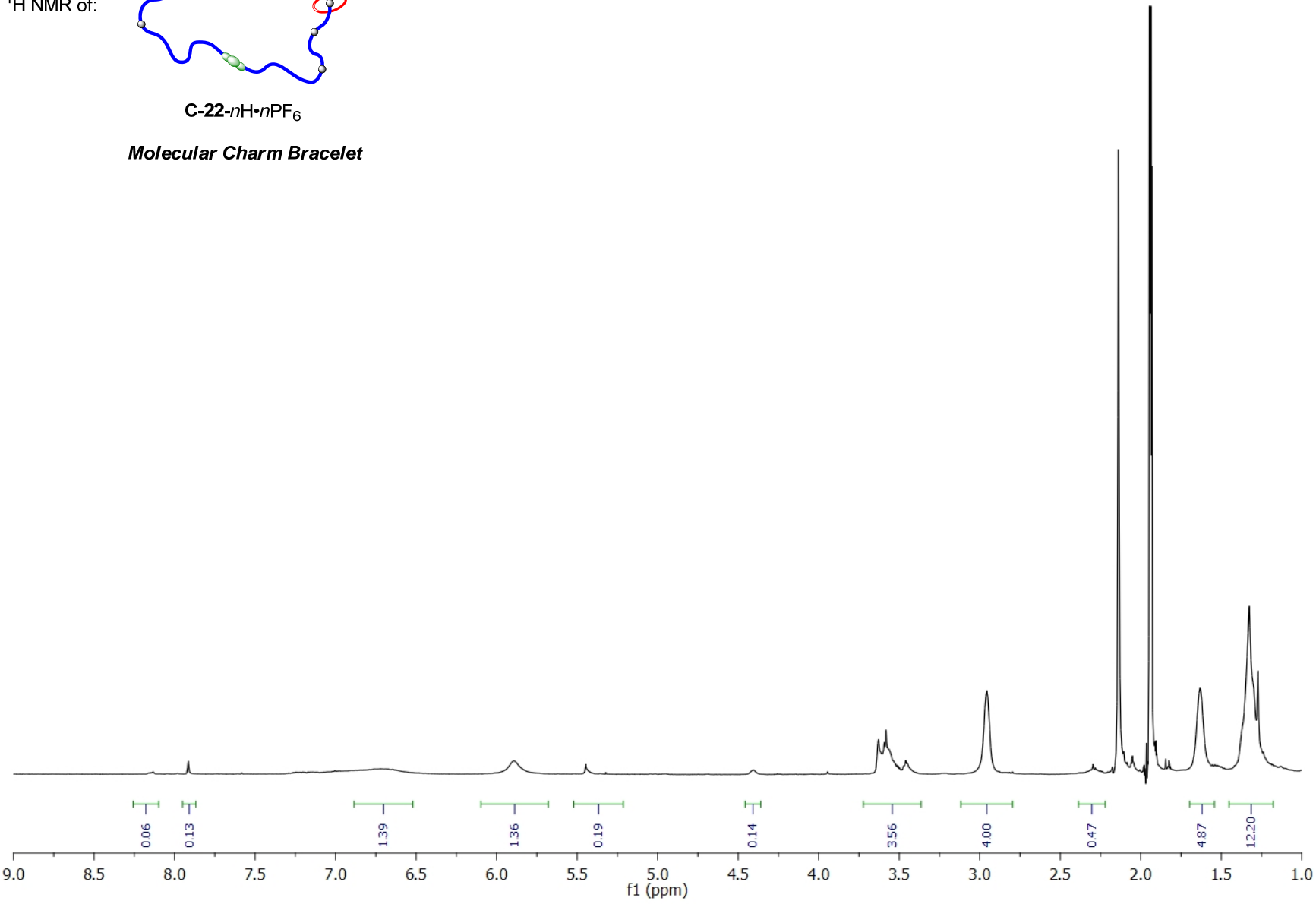
L-18-*n*H•*n*PF$_6$

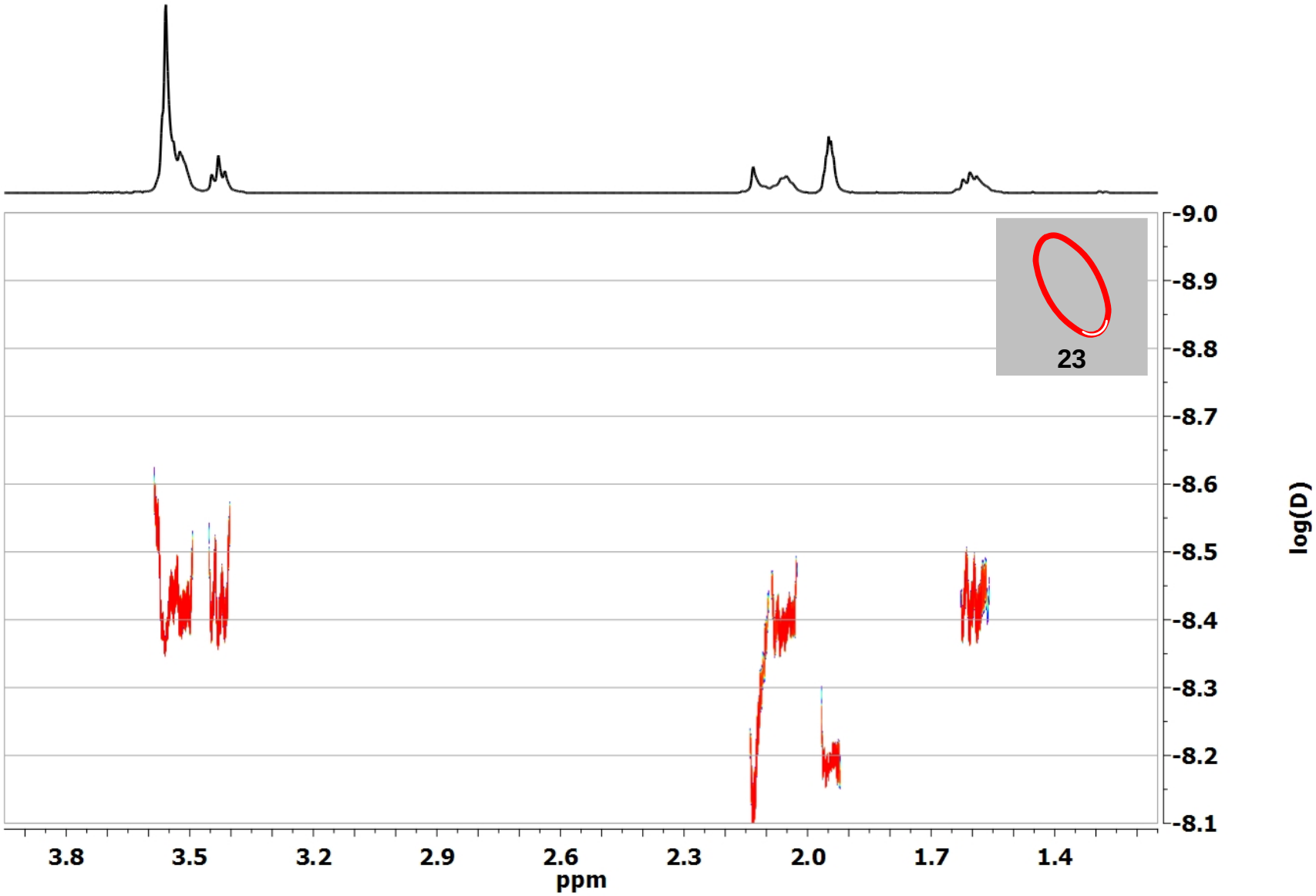
^{1}H NMR of:

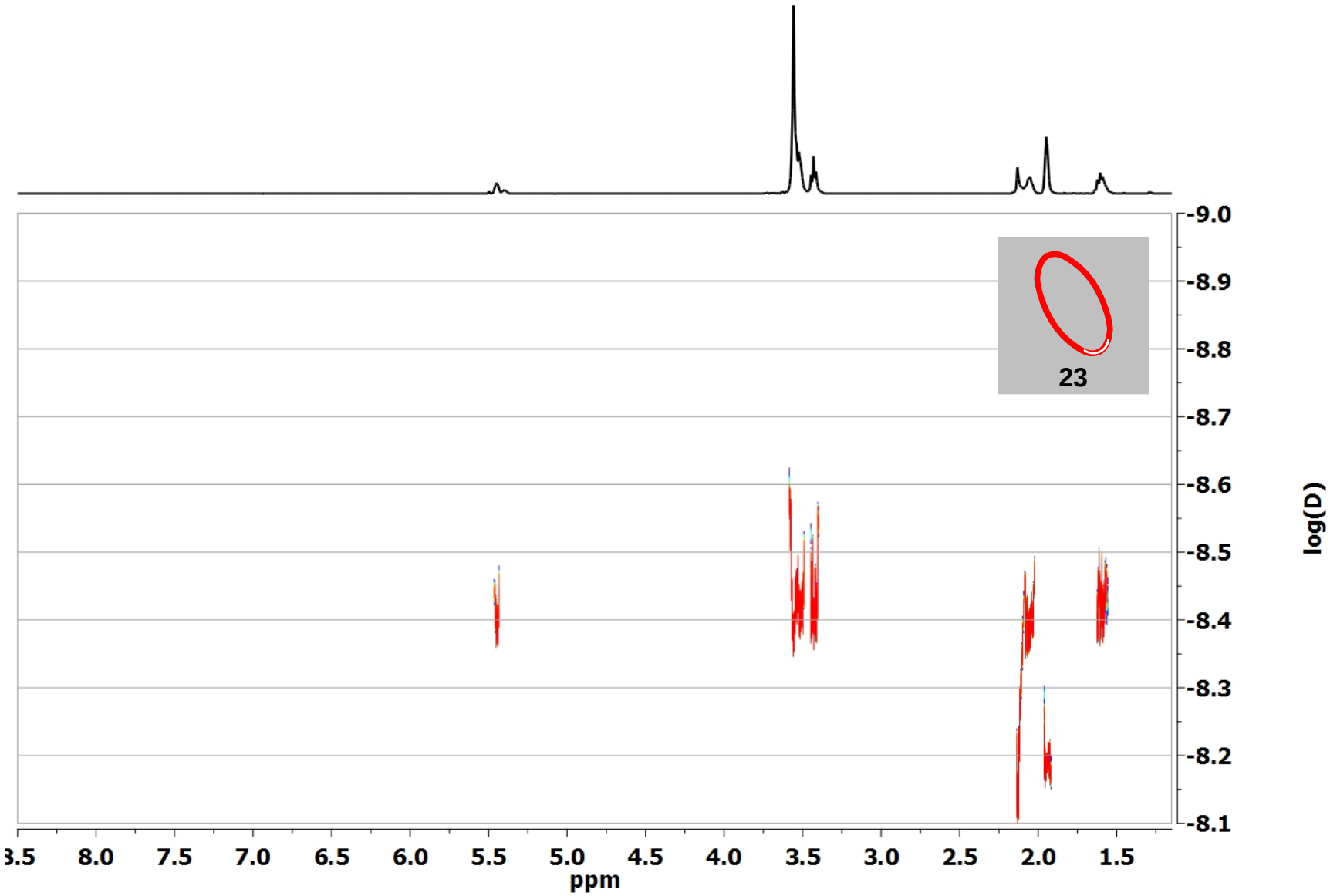


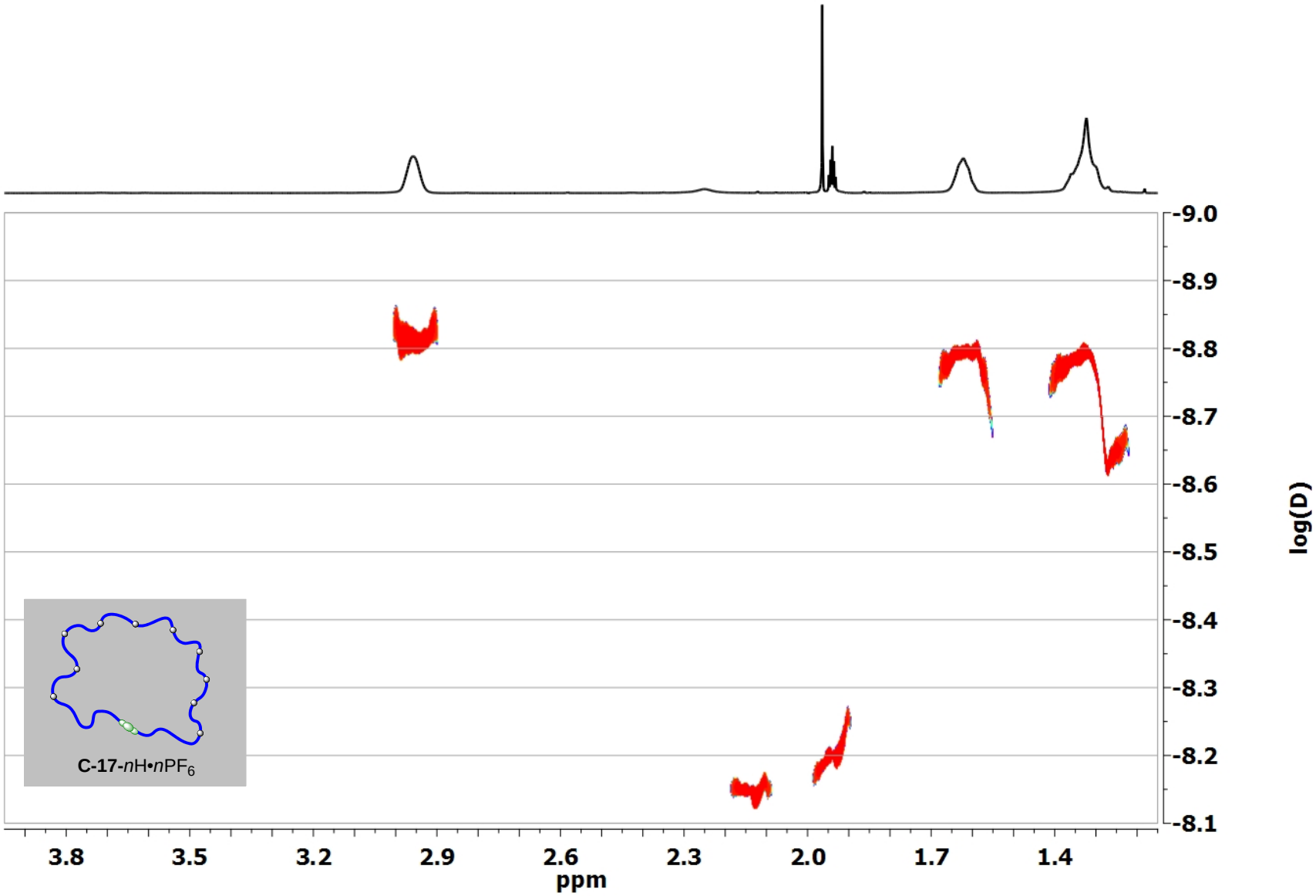
C-22-*n*H•*n*PF$_6$

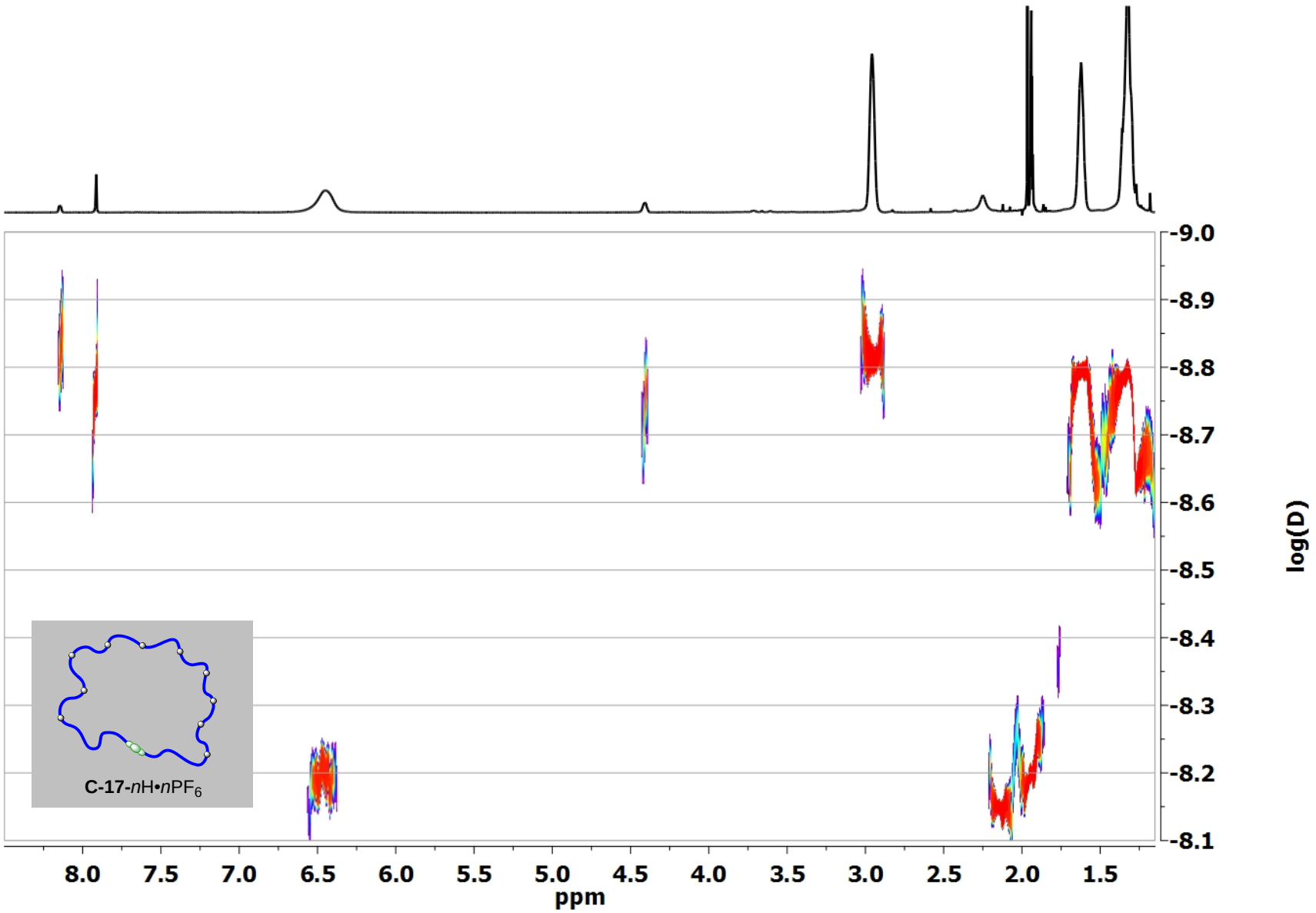
Molecular Charm Bracelet

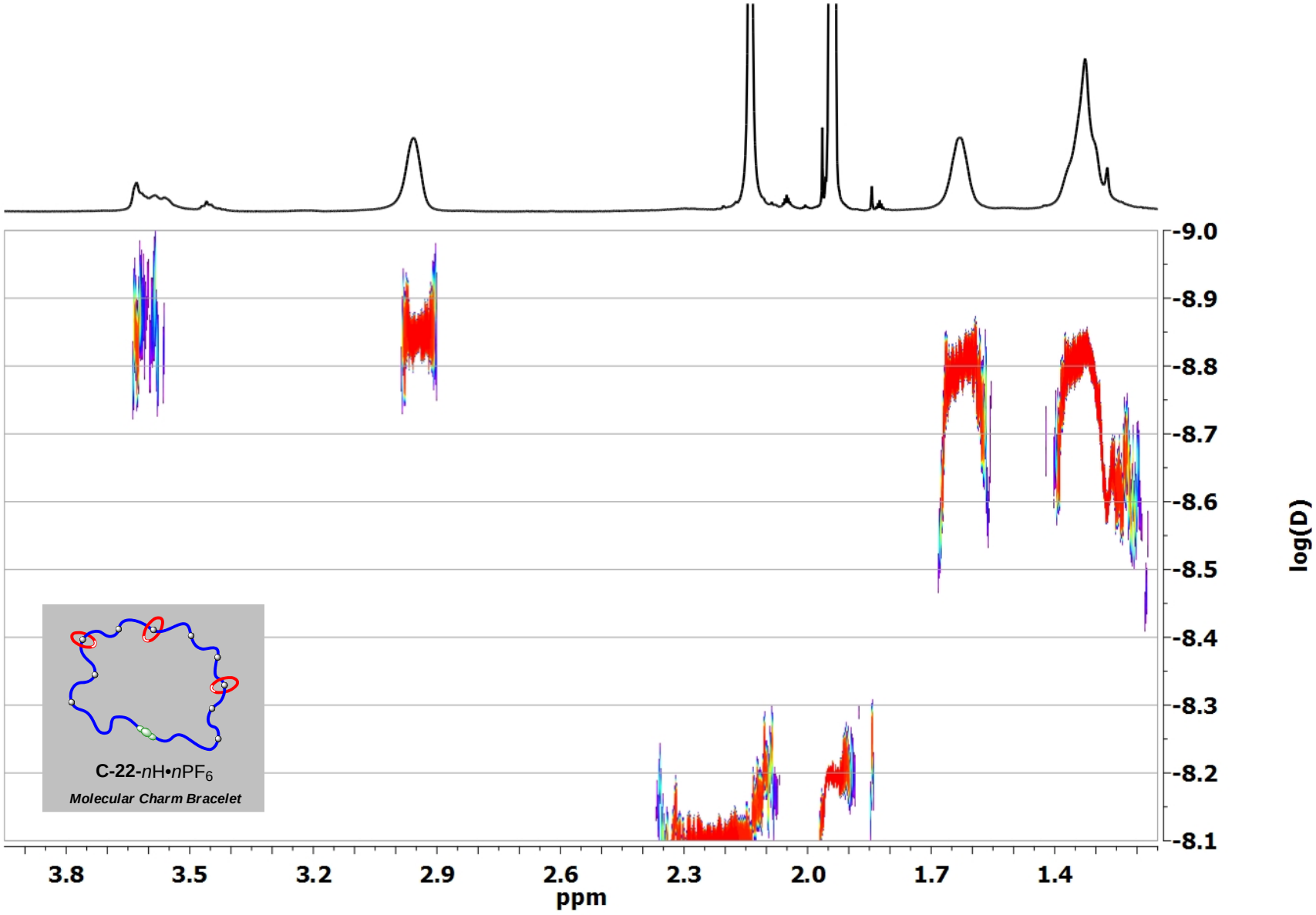


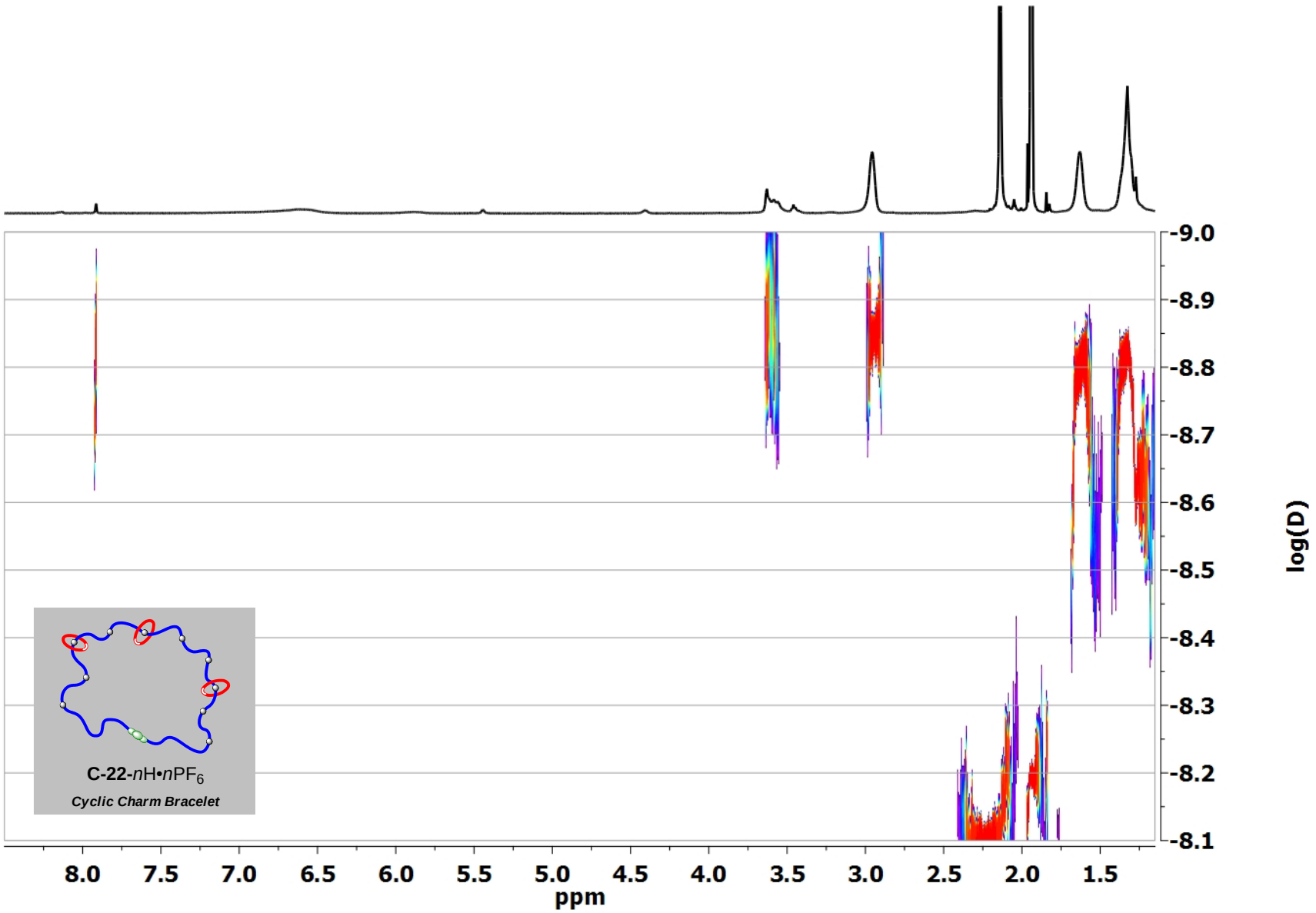

23
-9.0
-8.9
-8.8
-8.7
-8.6
-8.5
-8.4
-8.3
-8.2
-8.1
log(D)
3.8
3.5
3.2
2.9
2.6
2.3
2.0
1.7
1.4
ppm

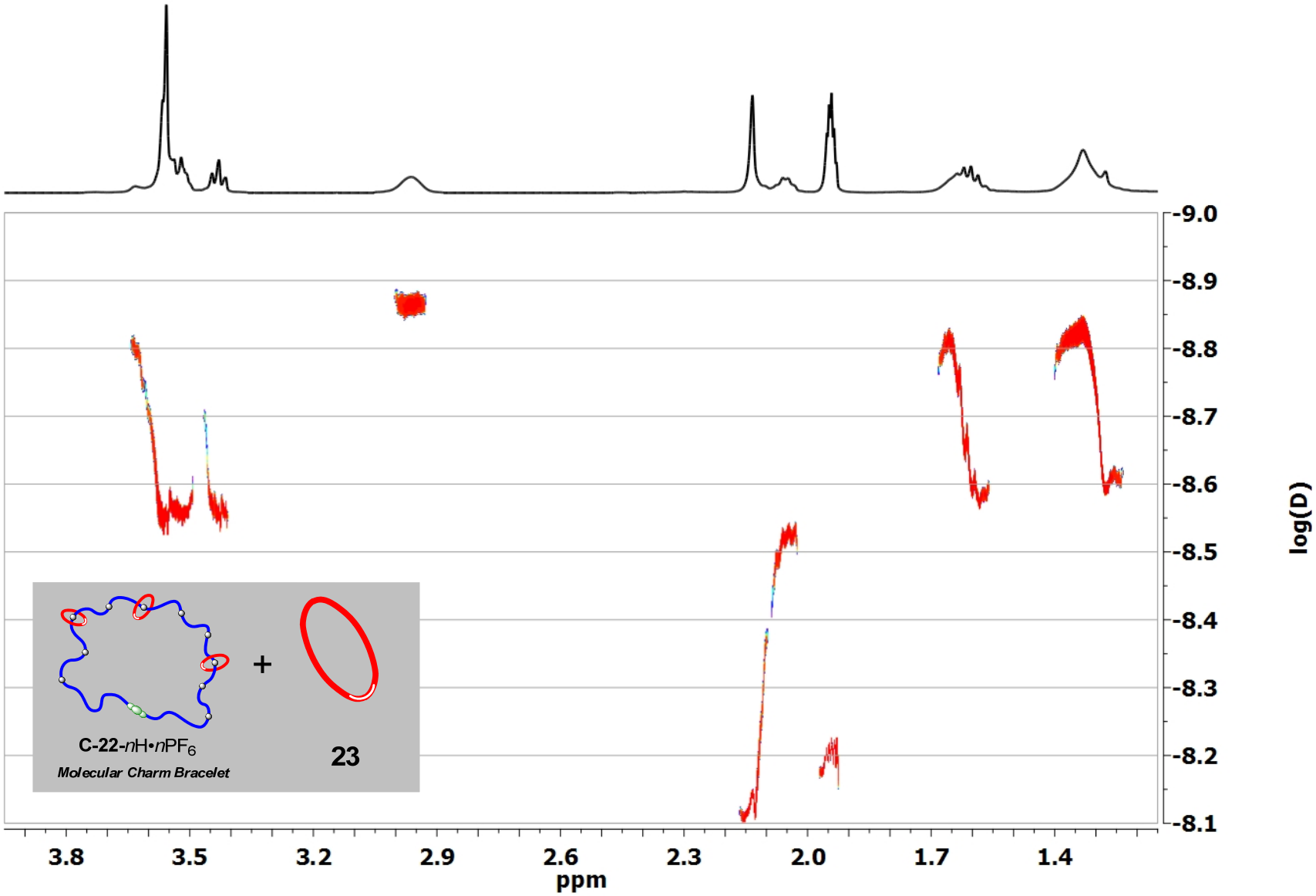

23
-9.0
-8.9
-8.8
-8.7
-8.6
-8.5
-8.4
-8.3
-8.2
-8.1
log(D)
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
ppm

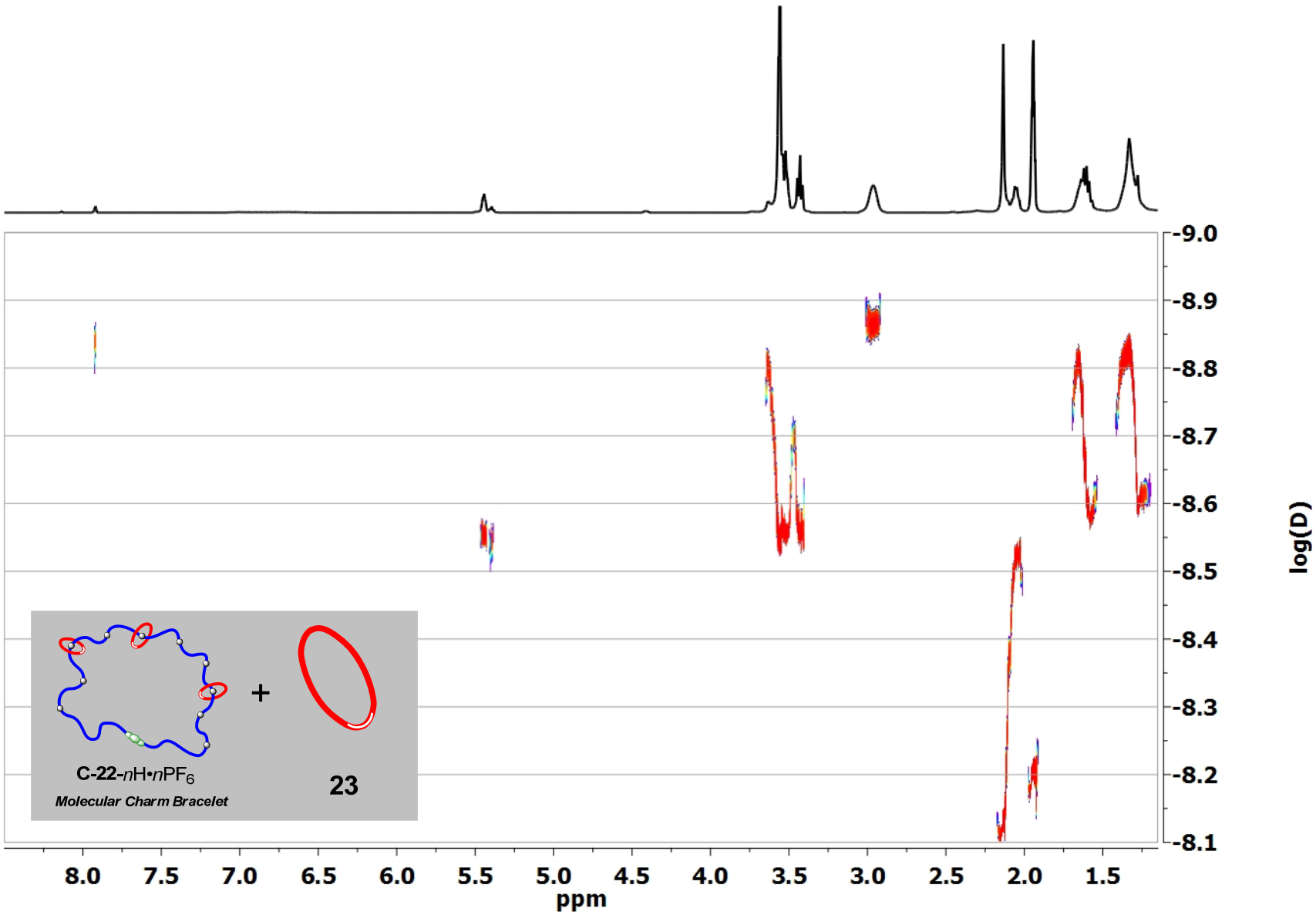

-9.0
-8.9
-8.8
-8.7
-8.6
-8.5
-8.4
-8.3
-8.2
-8.1
log(D)
3.8
3.5
3.2
2.9
2.6
2.3
2.0
1.7
1.4
ppm
C-17-nH•nPF6


-9.0
-8.9
-8.8
-8.7
-8.6
-8.5
-8.4
-8.3
-8.2
-8.1
log(D)
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
ppm
C-17-nH•nPF6

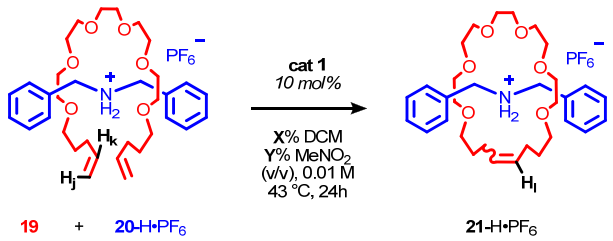

-9.0
-8.9
-8.8
-8.7
-8.6
-8.5
-8.4
-8.3
-8.2
-8.1
log(D)
3.8
3.5
3.2
2.9
2.6
2.3
2.0
1.7
1.4
ppm
C-22-nH•nPF6
Molecular Charm Bracelet


-9.0
-8.9
-8.8
-8.7
-8.6
-8.5
-8.4
-8.3
-8.2
-8.1
log(D)
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
ppm
C-22-nH•nPF6
Cyclic Charm Bracelet

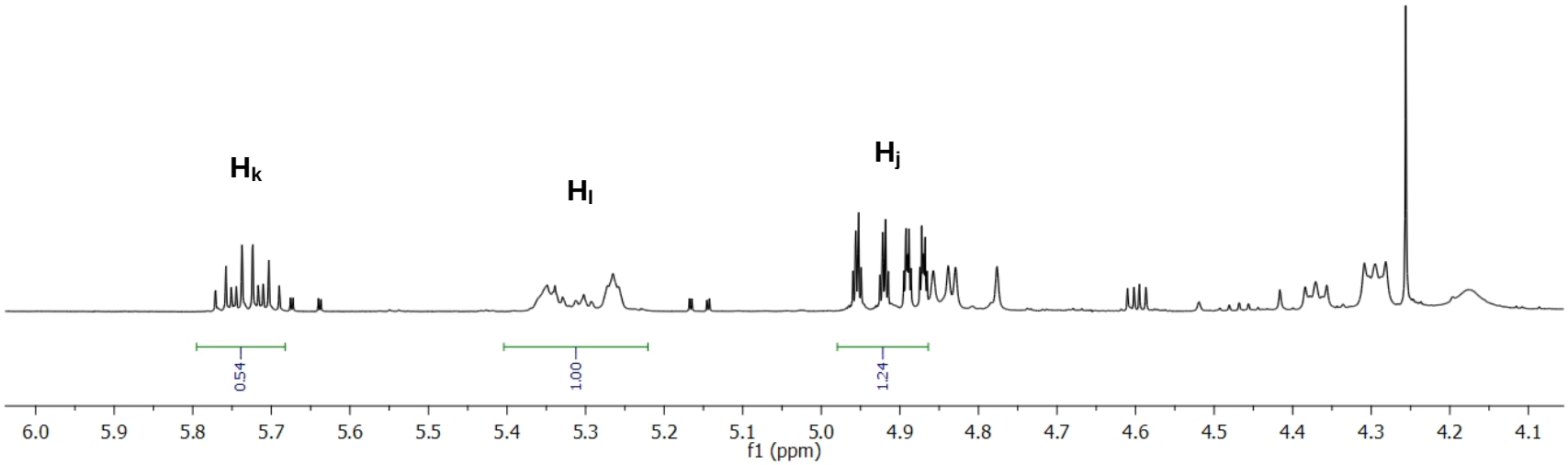

-9.0
-8.9
-8.8
-8.7
-8.6
-8.5
-8.4
-8.3
-8.2
-8.1
log(D)
3.8
3.5
3.2
2.9
2.6
2.3
2.0
1.7
1.4
ppm
+
C-22-nH•nPF6
Molecular Charm Bracelet
23


-9.0
-8.9
-8.8
-8.7
-8.6
-8.5
-8.4
-8.3
-8.2
-8.1
log(D)
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
ppm
+
C-22-nH•nPF6
Molecular Charm Bracelet
23

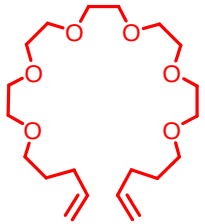
^{1}H NMR of ***ENTRY 5***:



19 + **20**-H•PF_6 → **21**-H•PF_6



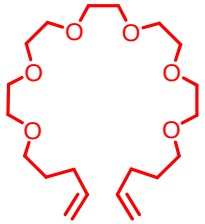
^{1}H NMR of:



19

1.59
3.38
20.00
3.87
3.73
3.82
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
f1 (ppm)

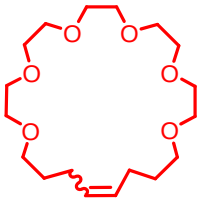
^{13}C NMR of:



19

138.49
114.88
77.48
77.23
76.98
70.91
70.82
70.80
70.80
70.31
30.44
28.98
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
ppm

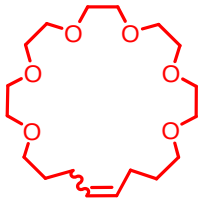
^{1}H NMR of:



23

1.84
19.97
4.04
4.00
4.05
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
f1 (ppm)

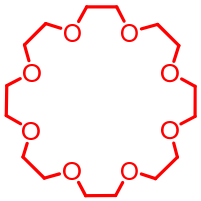
^{13}C NMR of:

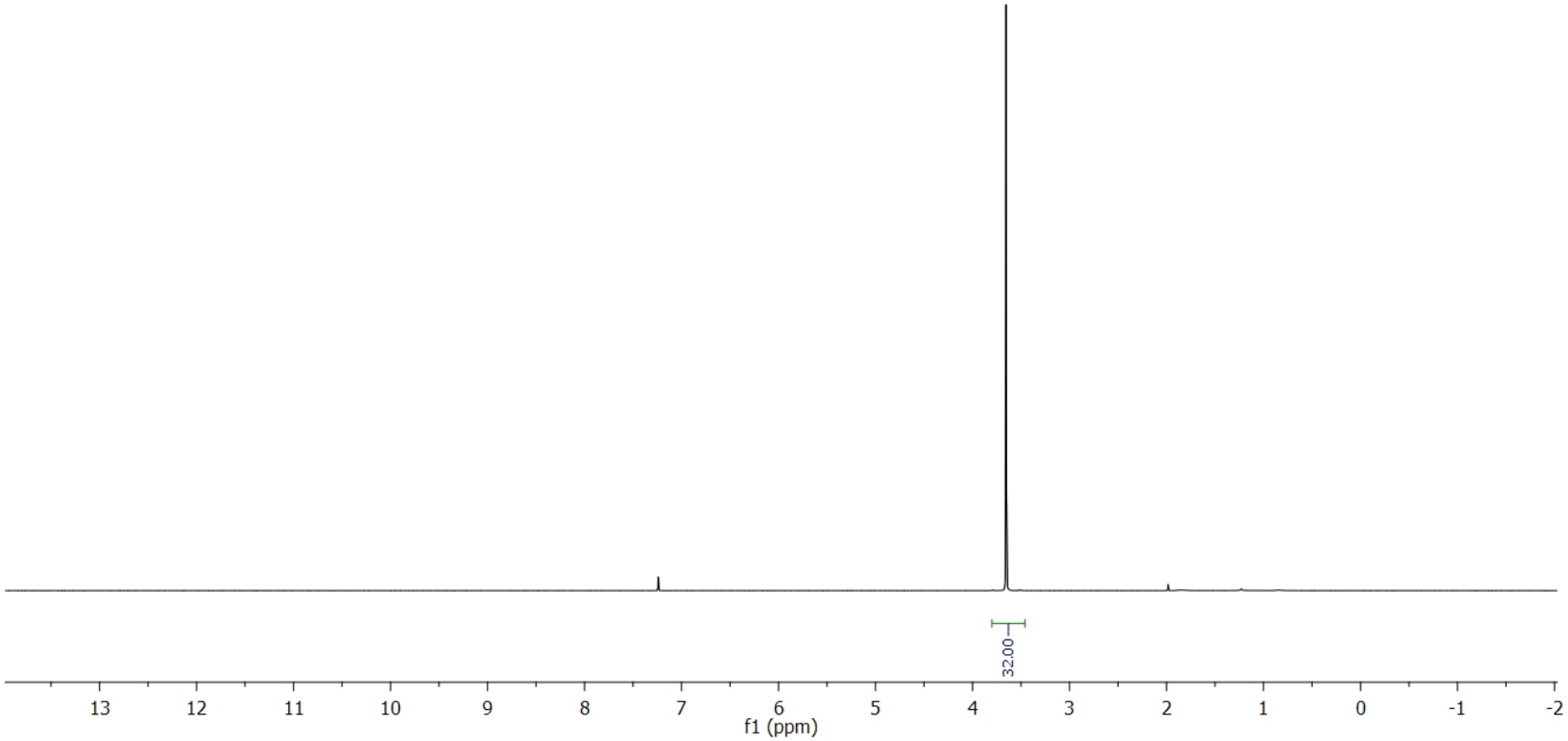


23

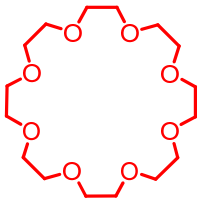
130.49
129.99
77.48
77.23
76.98
71.03
70.99
70.95
70.88
70.67
70.59
70.41
29.78
29.40
29.02
23.93
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ppm

^{1}H NMR of:





^{13}C NMR of:



77.48
77.23
76.98
71.05
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
ppm